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SPECIAL STUDY ON ECONOMIC CHANGE

VOLUME 3

RESEARCH AND INNOVATION: DEVELOPING A DYNAMIC NATION

STUDIES

PREPARED FOR THE USE OF THE

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OF THE

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LETTERS OF TRANSMITTAL

DECEMBER 26, 1980.

To the Members of the Joint Economic Committee:

Transmitted herewith is a staff study, printed separately, and technical papers which together form Volume 3 of the Special Study on Economic Change (SSEC).

Volume 3 is entitled "Research and Innovation: Developing a Dynamic Nation" and is one of 10 areas on different aspects of the economy published by the SSEC. The SSEC was initiated in 1978 under the direction of the former Chairman of the Joint Economic Committee, Representative Richard Bolling, then Vice Chairman Senator Hubert H. Humphrey, and the former Ranking Minority Member, Senator Jacob K. Javits. It is intended to identify major changes in the economy and to analyze their implications for policymakers. The successful completion of this Study will, I believe, help provide an economic agenda for the United States for the decade of the 1980's.

The views expressed in the technical papers are exclusively those of the authors and do not necessarily represent the views of the Joint Economic Committee or of individual members. The staff study was approved by the Chairman's Special Study Review Committee formed by the Chairman, Representative Bolling, Ranking Minority Member Representative Clarence J. Brown, and Senator Javits.

Sincerely,

LLOYD BENTSEN,
Chairman, Joint Economic Committee.

DECEMBER 22, 1980.

Hon. LLOYD BENTSEN,
Chairman, Joint Economic Committee,
Congress of the United States,
Washington, D.C.

DEAR MR. CHAIRMAN: Transmitted herewith is a staff study, printed separately, and technical papers entitled "Research and Innovation: Developing a Dynamic Nation," which constitute Volume 3 of the Special Study on Economic Change (SSEC).

The SSEC was initiated under the leadership of former Chairman of the Joint Economic Committee, Representative Richard Bolling, Vice Chairman Senator Hubert H. Humphrey, and former Ranking Minority Member, Senator Jacob K. Javits. The Study is divided into 10 substantive areas, which together chart major changes in the economy and analyze their implications for policymakers. Volume 3 outlines the connection of research and innovation to this Nation's standard of living and economic expansion and, in particular, to productivity growth and international competitiveness.

Sluggish productivity growth and high inflation marked the U.S. economic scene during the 1970's. Factors contributing to the listless economic pace included a slowing rate of innovative activity and lower levels of investment, both in terms of R. & D. outlays and the number of personnel devoted to R. & D. activities. U.S. expenditures for R. & D. relative to GNP, have been on the decline while those of major economic competitors such as Japan and Germany have been increasing. This study outlines a Federal R. & D. policy program of industry-government cooperation to improve the rate of U.S. technological development.

It should be understood that the views expressed in the technical papers are exclusively those of the authors and do not necessarily represent the views of the Joint Economic Committee or of individual members. The staff study was approved by the Chairman's Special Study Review Committee formed by the Chairman, Representative Bolling, Ranking Minority Member Representative Clarence J. Brown, and Senator Javits.

Sincerely,

JOHN M. ALBERTINE,
Executive Director, Joint Economic Committee.

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INTRODUCTION

By Walter A. Hahn*

CONTENTS

The supporting Research and Innovation Area Study (RIAS) of the Special Study on Economic Change provides a contextual and informational base for subsequent congressional policy analysis both directly related to research and innovation matters, and for considering research and innovation as an integral part of the total study of national economic change in a global context. Specifically, the RIAS report attempts to document what is known about the role of innovation in economic affairs, past trends and the present state of the innovation "system," and the outlook and some options for the future. These papers are designed for use both in the broader Special Study analyses and option reviews and by the Members of Congress in subsequent foresight, policymaking, legislative, investigative and oversight actions. An early conclusion was that few additional detailed analytical studies of research and innovation specific subtopics were needed for SSEC purposes. The quantity and quality of numerous past studies and the relatively rich research literature of this field have made it possible to prepare a variety of review and synthesis papers and to assemble selected revelant key documentation. Where current thinking has gone beyond the available literature, several new papers were commissioned. Where the source material was determined to be out of print or extremely hard to find, as for the 42 innovation studies of the last two decades, reprints and abstracts are made readily available in the appendix.

Studies of "innovation" are usually based on some explicit analytical model. No one of the dozens of models used in prior innovation studies seemed particularly adequate for this very broad and farsighted Special Study. The one conscious model used in this area study

*Research and Innovation Area Director; Congressional Research Service, Library of Congress.

is the systems model. Research and innovation are presented in a systems context. In conventional systems analysis fashion the elements of the innovation system are dealt with both separately in the context of their relationships to each other. Simultaneously (also in conventional "systems fashion") innovation is perceived as a subsystem of the larger economic and social whole. The one overriding theme, perhaps even conclusion of this Area Study, is the necessity to view innovation in the system/sub-system contexts described above.

Three time frames are explicity treated in the RIAS Report. The first time frame is the recent past—going back no more than two decades in a rather comprehensive review of the innovation literature. The second time frame is the present—the two plus years the Special Study was in process. Included are the results of a RIAS workshop of current innovation researchers and policy analysts. Also in the present time frame are the several especially commissioned papers recording emerging issues and concepts relevant to technological innovation. The third time frame is in the science and technology outlook and review of future innovation possibilities, extending three decades into the future. The emphasis in the outlook is on the 15-year center of the time distribution. The first five years of the period (1980–85) are accepted as essentially "given" or with so few options that they may be regarded as extrapolations of the present. Put another way, any policy or program options selected now cannot be expected to demonstrate much impact on society or in the economy prior to 1985.

In summary, the Research and Innovation Area Study emphasizes what has been learned in the last two decades, reviews current analyses and actions, and identifies the major societal and economic impacts of and on research and innovation likely to occur in the middle of the next three decades.

OVERVIEW

"Innovation" has emerged in the last two years as a national hot topic. Technologists and businessmen see it as being stifled, or at least retarded, by regulatory and "micro-management" barriers. Business magazines say our national innovation "elan" is gone. Also "gone" (according to some inventors) are sufficient rewards for entrepreneurial risk-taking a stable environment for initiating long-range endeavors. Those concerned with improving economic affairs are recognizing innovation as an essential element in the satisfactory performance of the domestic and global economies. They also are becoming aware that the health of the economy is a major factor in the health of innovation.

Those who study the innovation process and its role in socio-economic activities, simultaneously, and correctly, point to a lack of awareness and use of much that is known and the continuing need for more appropriate theory and for reliable and meaningful data. Consumer, envronmental, and labor groups have varying concerns for the negative impacts of present levels of innovation.

Politicians are faced with resolving the competing claims of all these groups, some of which are pushing for more and others for less government intervention and by means often in severe conflict. The pressures to resolve these differences are increasing much faster than clear and accurate knowledge upon which to base action and to assess consequences. Additionally, those who must resolve these issues find themselves bound by the precedents and constraints of both public and private institutions designed for simpler times and situations.

From the materials gathered in this study it is clear that there is no simple, quick, or overall solution to the "innovation problem." One reason there is no consensus about the problem is that there are many interrelated problems—and opportunities. Another reason is the complexity and interactive nature of all of the elements. This applies both within what this study has called the "innovation system," and with two-way relationship between the innovation system and the large set of national and global social, economic, and political affairs. A corollary to this is the need for parallel action at first, the macro policy and strategic level set of issues, and second, actions on individual functional and industry sector issues.

There is debate as to whether or not there is an objective innovation problem (or problems) or whether it is just the subjective perceptions of certain people. For public and private policymaking purposes it does not seem to make much difference what the answer is. If industry, Government, consumer, and other group representatives believe things are not going well they will behave accordingly. And if that behavior hinders the achievement of social and economic goals, legislative and executive government officials will be pressured and have a responsibility to deliberate and possibly to act.

It is also very clear that the traditional separation of Government interests from private industrial interests in the United States has developed some negative and confusing overtones. Some industries want less "interference" in regulatory affairs, others want selective protection from foreign competitors, while still others seek Government bail-outs. International traders simultaneously want more freedom, "Let's not export our antitrust and bribery laws to other cultures," and more help, "Why can't we be more like Japan Incorporated and have our Government behind us in international competition?"

Serious misunderstandings, ignorance of each other, and perpetuation of old or false myths abound between industry and Government. Mutual trust and respect appear generally to be very low. It seems clear that any improvements in innovation and economic affairs must include specific efforts to improve communications between the two sectors and to develop means for cooperative analysis, planning, and action. The situation is sufficiently polarized so that no sector or single institution can be very effective through unilateral action.

A major essential goal of all parties must be to increase stability and predictability. The actions of many of the parties in coping with each other come as surprises, which in turn generate reactionary responses, often with negative consequences for all. Defensiveness, the search for "blame," and an ever-shortened outlook by all sectors, are among the responses observed.

Restoring mutual trust and respect; developing cooperative analytical, policymaking and assessment mechanisms; and creating a stable innovation environment are admittedly vague and difficult to achieve. Nevertheless, the constant search for "solutions" and options throughout this study reveals no other more important or consistent underlying factors.

Government, and particularly the legislature, would seem to be the principal party to take the initiative and to provide leadership in such basic human and institutional matters. Neither the Congress, nor any other institution, can legislate trust, true cooperation or stability. But it can take a number of actions that, both in their ends and through their means, can move toward an improved climate. The hundreds of individual proposed actions cited in the papers to follow fall into a finite number of broad tractable but related categories:

Increase the flow of capital for innovative activities.

Improve the effectiveness of the patent system.

Enhance the ability of United States firms to meet international competition.

Improve the "technology base" that underlies many firms or several industrial sectors.

Face the issue of Government incentives for individual (or small groups) of potentially healthy firms in parallel with concern for weakened ones.

Actively and cooperatively search out regulatory and other barriers to productive and innovative endeavors and, at least on a trial basis, remove them.

Permit (experimentally at first) cooperative actions among firms where the public interest is served in parallel with the separate private interests of the firms.

The point is not whether the above list is complete (it is not) or right, but it does appear to be supported by the Research and Innovation Area Study. The point is the need to select a few key, mutually agreed upon, priority areas for action and to use them to change the present trends and relationships. The rub is that to be effective, each action must be taken in the light of its impact on all the other actions. While the innovation "problem(s)" must be viewed holistically, there is no such thing as a holistic or single "solution." One way to start grappling with this situation where everything seems to be related to everythng else, is to view it as three interactive levels:

View innovation as both a contributing element in socioeconomic affairs and one requiring guidance from society and resources from the economy.

View innovation as a system of interconnected functional elements (e.g., capital, anti-trust, R. & D., patents).

Deal with the specific and unique aspects of individual industrial sectors and possibly some individual firms.

It may be that the Nation is approaching the point where some action, even if imperfect, may yield far better returns than continuing the present pattern of waiting until sure, or reacting suboptimally to a variety of crises or special interest demands. The pressures for action are mounting. The knowledge to take a variety of experimental and some permanent actions exists. The rewards in increased social and economic well-being would seem to exceed the risks of partial failures and greatly exceed those of maintaining the status quo.

The complexity, scope, and knowledge base of the innovation "problem" does not permit "solving" it by listing a few key policy or program options with accompanying pro-con analyses. This is neither a statement of hopelessness nor of pessimism. Rather it supports that this study has found no simple, quick, or easy approach to improve the innovative capacity of the Nation and, by implication, to improve its economic and social well-being. But the study does demonstrate, however, that our knowledge of how the innovation system works is better and more extensive than many perceive. Unfortunately, we know much more about the individual elements of the innovation process than we do about how to put them together. Both the greatest opportunities, and the greatest difficulties, lie in integrating innovation with the broader pattern of socio-economic affairs.

We know we lack adequate comprehensive theory, models, and in some areas, we also lack reliable data and measures to know in advance which policy, program and institutional changes will prove effective. Does this mean that nothing can be done? The records of both the executive and the congressional branches to implement recommendations based on analytical studies of innovation are poor over the past 10–20 years. Why have the recommendations of so many blue ribbon panels, analytical studies, statements in hearings, and in the media, not been implemented or even tried experimentally? The question is posed rhetorically, for this study, like its predecessors, has not produced the answer to that question.

Some academicians and bureaucrats accept the lack of theory and certainty as justification for inaction. Others decry the inertia and cultural lag of our institutional forms and procedures. Some label it a failure of nerve—someone else's. Each finger-pointer has at least one other group to blame: too much (or not enough) Government, irresponsible business, big labor, a consumer society, inflation and a faltering economy, or just plain "them," referring to everyone from environmentalists to OPEC, and from political opposites to foreigners. There is no consensus on what is the problem, but there does appear to be consensus that there are problems, that the state of innovation is less than desirable or possible, i.e., opportunities for improvements exist, and that something needs to be done, now.

The dual hazards of consensus and proof must be cautioned against. While there appears to be consensus on a variety of issues and "solutions" to innovation problems, it is possible in some cases that consensus is not firmly supported by empirical data and relationships. As was noted earlier, however, in cases where people believe something to be right or desirable, they will behave in consonance with their beliefs. Thus, action may be required by the policymaker anyway. In many cases there is substantial evidence supporting certain findings, but it may fall short of standards of scientific or legal proof. Also, as was suggested earlier, logically this may not be sufficient cause for inaction but is often offered as an acceptable excuse. Some of the complex interrelationships concerning innovation may not be known in the time frame needed for remedial action or new initiatives, even if imperfect. And some may just be unknowable.

Amplifying details and supporting evidence have been deliberately sacrificed in the foregoing overview in order initially to communicate a synoptic view of the status of industrial innovation. Complete detail and documentation are contained in the accompanying Research and Innovation Area Study (RIAS) papers.

Some Congressional Options

The purpose of this Research and Innovation aspect of the Special Study on Economic Change was: (a) to provide a synthesis of what is known about the innovation process and its role in socioeconomic affairs; (b) to present this in the light of current actions, debate, needs and opportunities; and (c) to offer some perspective on long range outlooks for the future.

The process of compiling this synthesis has revealed several major findings and option paths of immediate interest to the Congress. There is growing recognition of the mutual reinforcement between a healthy economy and vital innovation. Similar to recognition of the Nation's poor general economic health there is widespread perception that the state of innovation is less than possible or desirable. The overwhelming mass of analytical policy and persuasive reports and the current hubbub of innovation writings and discussions create a climate demanding action. The focus of that demand—or opportunity—is now the Congress.

There is a wide variety of congressional action options that are open to Congress. Broadly, they fall into five categories that can be approached to parallel:

(1) Concerted action on the menu of already introduced bills related to innovation.
(2) Swiftly reacting to proposals from the executive branch—especially the President's messages on industrial innovation and economic revitalization.
(3) Reviewing the several recent major innovation studies (including this one) for actionable items and developing a broader perspective on innovation.
(4) Initiating steps to improve and stabilize the general climate both for substantive innovation in the private sector and for participative innovation policy and program planning between the public and private sectors.
(5) Initiating broad foresight and assessment activities for systematic and continuing action coupled with a few *selected* analytical efforts to answer key questions identified in the other four areas.

Within each of the five foregoing interrelated and parallel action categories, the range of options for congressional action is considerable.

Coordinated Legislative Action

Depending upon one's definition of "related to innovation," there were between 30 and 200 such bills before the 96th Congress. Some are well along in the legislative process while others have been recently introduced only for discussion purposes. A few are broad policy and organization oriented proposals but most deal with specific aspects of innovation like tax incentives, productivity, small business, patents, and research and technology. The specific menu of bills and their current status are reported in detail in the Congressional Research Issue Brief Industrial Innovation which can be obtained in current updates directly from CRS. A key point arising from this Study is to suggest that in the debate and consideration of each of these separate bills, specific and continuing attention be given to possible interrelationships and mutual impacts among the many bills and possibly with existing status.

Among the more visible recent integrating activities that contribute to systematic Congressional consideration of individual actions toward improving the climate for industrial innovation are the following: this Study and other activities of the Joint Economic Committee, the House Task Force on Industrial Innovation, and the several continuing coordinated activities between the House Subcommittee on Science, Research and Technology with the Senate Subcommittee on Science, Technology and Space. Additionally, several Senate committees are exploring formation of an information staff group for coordination of innovation matters.

Two events illustrate what may be precedents for many similar future coordinated Congressional activities. One was the House Colloquy on Industrial Association held on December 13, 1979, and which involved over 20 Members. Another was the afternoon following the morning release of the President's Message on Industrial Innovation on October 31, 1979, when four Congressional Committees held joint hearings on the message, viz; the Senate Committees on Commerce, Science and Transportation and Select Committee on Small Business plus the House Committees on Small Business and on Science and Technology.

The President's Messages on Industrial Innovation and on Economic Revitalization

The President's Message on Industrial Innovation of October 31, 1979, identifies 31 specific actions, at least half of which invite some form of congressional involvement. Based on early reactions (and excepting patents) primary congressional interest appears to be in those initiatives in the tax, capital generation, and regulatory areas that were absent from the President's Message. Many other actions are within existing authorization authority and can be dealt with in normal appropriation procedures. Several areas of R. & D. funding priorities are less clear. Research and development can be and often are major direct contributors to successful innovation. But innovation can and does proceed without a direct link to R. & D. Ultimately, of course, research, development and innovation depend upon a continuously growing body of knowledge stemming from basic or fundamental research. Independent of the current innovation malaise there are strong and separate arguments for a steady support of basic research by the Federal Government. The present Administration and recent Congresses have demonstrated awareness of this and the downward trend of Federal budgets for basic research has been reversed. In spite of the ever present demands for more R. & D. funding in some disciplines or toward solving specific problems, there appears to be a consensus that sufficient public and private funds are being applied for R. & D. More of it may be going into shorter range pursuits than desirable and possibly too much of it is "defensive R. & D." directed toward meeting regulatory requirements rather than generating novel capabilities.

There is growing concern that the so-called "generic technologies" are undersupported. Generic technologies are those not in the single interest of any one firm (or governmental agency) like materials, welding, or corrosion control. They are the technologies that underlie many firms or entire industrial sectors. A number of R. & D. and innovation studies and the President's Message on Industrial Innovation call for increased government support of the generic technologies. Closely related are three Presidential proposals for better industry-university cooperation in R. & D., for a small business innovation program, and the establishment of corporation for innovation development. All of these appear to be priority aspects of R. & D. funding for congressional attention. Most of the other Presidential initiatives would seem to come under normal oversight processes.

On August 28, 1980, the President issued a statement on his Economic Program for the Eighties. It emphasized industrial "revitalization" with specific attention to selected tax measures and restoration of part of the cuts in Federal research and development investment made in earlier budget proposals. Also with respect to industrial innovation, the message called for creating "new partnerships . . . to foster cooperation between government and the private sector in dealing with the complex issues of industrial policy . . ." Specifically, business, labor, and public representatives were to be appointed to a new President's Economic Revitalization Board. In addition to dealing with worker displacement and training and improving productivity the new Board is to make proposals for the establishment of an industrial development authority. Eighteen specific proposals were made, several requiring Congressional action.

Review of Major Innovation Studies

Like most studies, this one raises many issues for further study and analysis. But it also presents almost overwhelming evidence that a priority first step is critical review of the plethora of existing well researched and often well articulated analyses and action proposals. For example, it was beyond the scope of RIAS to determine which of the 205 conclusions and recommendations extracted from the 42 past innovation studies have been rejected or acted upon, which are in conflict (thus offering specific alternatives), and which are viable options for immediate congressional action. In the many parallel (to RIAS) innovation studies cited later in this introduction are over 300 more conclusions, recommendations, and options for action. Several committees and subcommittees of both houses may wish to cooperate in conducting such a review and in deciding which, if any, of the initiatives might best be pursued under their respective jurisdictions.

Improving the National Climate for Innovation

In the Overview of this introduction to RIAS, it is stressed that two overriding considerations in any congressional action are the interrelatedness of each activity with the many others, and generating an overall climate for positive and participative action between Government and the private sector. Implied within this is increased understanding and cooperation among the branches and levels of Government. All sectors are looking for a clear steady signal as to the direction and priorities of national innovation activities and of their relative rolls as contributors and beneficiaries. If it were only possible to legislate effective communications and mutual trust and respect among the many actors in the innovation process, that would certainly be a priority recommendation of this study. It should, however, be a priority goal and consideration in all congressional activities related to innovation.

Foresight and Assessment

It is tempting in any report like this to identify key substantive areas of technology for priority attention. The examples of the concerted efforts of the Japanese in video recording and now in robotics are often cited. Similarly the United Kingdom is focusing on selected aspects of information technology, and Sweden on forest products. There is no consensus nor any analytical arguments as to which set of technologies the United States as a nation should optimally pursue. Most science and technology outlooks (including this one in RIAS) strongly suggest that the "post industrial society" will turn out to be an "age of information"—to be followed by an era of "biotechnology" early in the 21st century. Information, computer and communications technologies are advancing very rapidly and are increasingly so entwined that the term "compunications" is approaching common use. Evidence is growing that suggests dramatic changes in biology and medicine stemming from progres in both R&D and clinical practice. The demands of the energy crunch are "pulling" energy supply and conservation innovations from all sectors of society. Innovation in transportation is similarly driven more by demand than by radically new technological possibilities.

The Science and Technology Outlook that follows in this report as well as similar foresight documents offer a wide range of scientific and technological possibilities and descriptions of unmet social, economic and environment needs and desires. But there appears to be neither need nor pressure for the Congress to select a few lead technology areas for the United States to pursue on a national priority basis to be more competitive in world markets. To the contrary, though far from consensus, there are strong feelings and arguments made for leaving this type of decision to the market forces, domestic and global. Congress, the executive agencies, and State and local governments can and will continue to invoke priority choices for innovation activity for meeting internal government and public needs and desires.

Another pervasive theme throughout RIAS is recognition of the long time span of the interacting elements of the innovation system. The time from invention to application and use of an innovation often exceeds a decade. Sometimes a decade passes before the full impact on society, the economy, or the environment is realized. This suggests the need for increased emphasis on foresight and assessment in policy planning and other legislative actions. Congressional actions on innovation matters today will have their major impacts on society in the 1985–1995 period—but they must start today if they are to have effect even then.

A variety of foresight, impact assessment, and policy analysis options are open for extending the outlook of decisionmakers. Beyond the traditional hearings and investigatory activities of committees is the requirement in the Rules of the House of Representatives for committees to "review and study any conditions or circumstances which may indicate the necessity or desirability of enacting new or additional legislation within the jurisdiction of that committee . . . (and) . . . shall on a continuing basis undertake futures research and forecasting on matters within the jurisdiction of that committee". This is known as "The Foresight Provision" to be found in Jefferson's Manual, Rule X, section 692(a). Foresight activities in the Senate are less formalized but were recognized by the Commission on the Operation of the Senate which recommended that the Senate "Establish in or through the Senate policy committees—restructured and staffed for the purpose—responsibility for assuring that appropriate standing committees identify and analyze major national problems before they become matters of public concern and hasty legislative action."

In 1976 Members from both houses joined in establishing the Congressional Clearinghouse on the Future. The Clearinghouse has sponsored dinners with prominent futurists for Members and informational seminars for their staffs. The Clearinghouse, with assistance from CRS, set up a Trend Evaluation and Monitoring (TEAM) project. TEAM serves as an early warning system of emerging issues. To keep Members informed of current and forthcoming developments, the Clearinghouse publishes a newsletter, "What's Next?" which is widely circulated on Capitol Hill and beyond. More recently, the Clearinghouse has formed the Congressional Institute for the Future, a nonprofit support group for analysis and consultation. In support of the array of activities above, the Congressional Research Service has developed a Futures Information Retrieval SysTem (FIRST) and a permanent interdisciplinary professional staff Foresight Team. Also, under the terms of the Legislative Reorganization Act of 1970, CRS is required "to advise and assist . . . in the analysis, appraisal, and evaluation of legislative proposals . . . so as to assist . . . in: (a) determining the advisability of enacting such proposals; (b) estimating the probable results of such proposals and alternatives thereto; and (c) evaluating alternative methods for accomplishing those results. . . ." CRS has the additional responsibility for preparing "emerging issues" reports for committees in each new Congress. In 1972, the Office of Technology Assessment was established with the "basic function to provide early indication of the probable beneficial and adverse impacts of the applications of technology. . . ." The Congressional Budget Office was established in 1974 to provide Congress with budget data and forecasts along with analyses to alternative fiscal, budgetary, and programmatic policy issues.

The point of all of the foregoing is to note that considerable information and institutional resources are available to help Congress perform its foresight and assessment roles with respect to research and innovation.

What Is Known?

A key paper describing the current state of knowledge is: "The Process of Technological Innovation in Industry: A State-of-Knowledge Review for Congress." One thesis of this paper is that, although knowledge remains limited, recent (e.g., in the past decade) research has resulted in more information about the process of industrial innovation than most policymakers realize. The objective of the paper is to summarize and translate the research findings into a form useful to congressional staff and Members. For purposes of this report, technological innovation is defined as the process by which society generates and uses new products and manufacturing processes. It includes the activities ranging from the conception of an idea to its widespread application by society. The activities include the generation, research, development, introduction, and diffusion of new and improved products, processes, and services for public and private use. Although civilian-oriented industrial innovation is largely a private sector activity, Government has an interest in its socio-economic impacts on the Nation as a whole.

Industrial innovation may be regarded as an investment activity, and like other investments, it responds to economic forces, such as demand and costs. It is also affected by technical and institutional factors, which guide the innovation and determine how rapidly innovation can respond to economic signals.

Innovation may be viewed as a process of uncertainty reduction. As the idea proceeds through the stages of innovation, the investment increases and information is produced that allows a firm to estimate more accurately a project's economic and technical potential. As the investment becomes larger, the evidence must increasingly point to the probability of profitable production to justify continuation. The various types of uncertainty involved in innovation are described, as well as their effects on innovation decisionmaking and the types of innovations that are undertaken.

Relationships between technological innovation and such aspects of industrial organization as firm size, industrial concentration, market entry, diversification, and spin-off firms have important implications for public policy. However, research findings have been largely contradictory and inconclusive. Recently developed theories of industrial life cycles may help explain some of these findings.

The diffusion of innovations among industry, which is the means by which an innovation's economic and social impacts are made, may take a long time. Factors affecting the rate of diffusion of innovations are similar to those affecting the generation of innovations: for example, the cost of the innovation and the advantage it offers. As an innovation diffuses through industry, it may change as it is improved and modified.

The time lags involved in the innovation process are often lengthy. However, it is not necessarily always beneficial to shorten the innovation process too much, since the lag may be caused by the absence of a market for the innovation, bottlenecks in related technologies, or negative societal impacts.

This paper's findings have implications for congressional decisionmaking for innovation policy. Listed here in brief form, they are discussed in more detail in the paper:

Innovation is a complex process and our understanding of it is limited;

The essence of innovation is uncertainty about the outcome;

The importance of market factors to industrial innovation is difficult to overemphasize;

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Innovation is a costly and time-consuming process;
The economic and social impacts of innovation are made through their diffusion;
Basic scientific research seems to underlie technological change in complex and indirect, but important ways;
The innovation process differs from industry to industry, sector to sector, and even firm to firm;
Financial and manpower resources are necessary, but not sufficient, for innovation; and
Both large and small firms play important roles in innovation and those roles differ from industry to industry.

In addition to academic research on innovation there have been a plethora of policy and issue studies by a variety of boards, conferences, contractual and in-house analytical teams, and a few by individuals. In the chapter entitled, "Two Decades of Research on Innovation: Selected Studies of Current Relevance," the authors have collected the many proposals for policy and action that may be still relevant but are largely unevaluated and untried. This collection provides, in one place and in abbreviated form, a selection of the executive summaries (or equivalent) of 42 prior studies. The selection is judgmental and was made by a network of research, development, and innovation analysts. The selection criteria are:

(i) Major studies dealing with the entire innovation system, and not only isolated factors within it;
(ii) Studies containing explicit public policy recommendations, or contributions, to the general understanding of innovation; and
(iii) Studies recent enough to be of continuing relevance to policy-making.

One example is "The Charpie Report" of 1967 which is still widely cited as a nonimplemented "classic" in this field. The 205 recommendations contained in these reports are extracted and grouped for ease of assimilation. A consolidated display of all recommendations attempts to show the action parties to which the recommendations appear to have been directed. Three categories of action parties are noted: policymaker, executor, and and impacted party. Brief statements of the 205 policy recommendation for stimulating innovation, are categorized into 14 policy areas which have been extracted from the 42 studies. Some of these recommendations, appear to overlap; others may be contradictory. Some are broad and general; other are narrowly focused. As a package, however, they represent candidates fo review and action because of their continued relevance and likely efficacy in stimulating innovation. The paper also presents brief abstracts of the central points of the 42 studies. Scanning these 42 sets of short paragraphs will provide a panoramic view of the last two decades of literature on innovation. Because most of the 42 documents cited are out of print and very hard to locate, the key summary or conclusion and recommendation sections have been extracted and reprinted in an appendix.

Taken together, these selections provide the main sources for much of the current understanding of the innovation system, and illustrate the many interconnected issues which must be faced by policymakers seeking to stimulate technological innovation. Likewise, the identification of action parties connected with the recommendation indicates how many segments of the Federal Government intersect with the innovation system, and suggests the need for integrated, and comprehensive policymaking. No in-depth evaluation of the individual recommendations, however, has been attempted here.

The final RIAS paper in the "known" category is "The Relationship of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity." This paper presents an overview of what is known about the relationship of Federal support of basic research in universities to industrial innovation and productivity. It reviews three kinds of evidence which bear upon this issue: the conceptual relationship between science and technology, the nature of university-industry relations, and economic studies of the contribution of research and development to economic growth and productivity.

The report reveals that there is widespread agreement among university, government, and industrial officials that Federal support of basic research in universities is an effective method of enhancing the science base for industrial innovation. However, economic studies have been unable to isolate the precise quantitative contribution of basic research (as opposed to applied research and development) to economic growth and productivity. The extent of institutional barriers between universities and industry may be obstructing the transfer of basic research results to industry preventing them from being embodied in new technology and thus contributing to improved economic productivity.

The report concludes that Federal funding of basic research in universities may be viewed as an investment that will have payoff primarily in terms of improved efficiency of the R. & D. process and major technological changes that may permit continued improvements in economic productivity in the long-term future.

Status

Realizing that the cutting edge of research and real-life practice are usually some distance ahead of much of the research and policy analysis literature, an attempt was made both to update, and to some degree authenticate, the picture presented in the foregoing papers. "Research, Innovation, and Economic Change" is a summary and analysis of the presentations and discussions of the December 1978 "synthesis" workshop attended by all SSEC Research and Innovation Area Study authors and staff, an approximately equal number of outside academic and industrial experts, plus participants from the President's Domestic Policy Review Study, National Science Foundation, and the parallel Committee on Economic Development innovation study. Among the major issues discussed were the innovation process, technology transfer, the linkages between innovation, economic growth and productivity, and the Government's role.

This workshop provided considerable insight into the linkages between research and innovation and economic growth and productivity. In the jargon of some of the analysts participating, "we have begun to see the systemic and holistic nature of the set of (innovation) processes under investigation." The outside participants gave the authors a feeling of increased confidence that the study team had achieved satisfactory coverage of the key topics in research and innovation.

The workshop was conducted for the study team by an external university group of science and technology analysts who produced a condensed and separate statement of the current state-of-knowledge about the innovation process and its role in the economy. Among the themes stressed during the workshop discussion were: the apparent decline in the vitality of U.S. technological infrastructure and the loss of an "innovative elan"; and the lack of definitive knowledge about the relationships between investments in research and development and desirable economic change. Although the workshop discussions produced no formal consensus on specific policy options, the general sense of participants was that: (1) there was a need for both remedial and anticipatory policy actions in the research, development, and innovation areas; and (2) there is enough knowledge, given the risk of no action, on which to base policy choice. Policy options identified in the workshop report as meriting particular attention include:

(1) Developing attitudes and mechanisms supportive of positive government-business relationships in the areas of civilian research and industrial innovation.

(2) Examining the organizational structure of the executive branch, with respect to its ability to carry out the Federal role in those areas, including the support of basic and applied research for industrial application.

(3) Identifying existing Federal policies and practices which act as barriers or deterrents to innovation, and where it is possible without compromising the primary objectives of those activities, modify them to remove or reduce their negative innovation impacts.

(4) Lessening congressional pressure (or at least correcting the perception of such pressure) for short-term evidence of the success of Federal actions in support of industrial innovation, including research support and support of demonstration projects.

(5) Developing incentives for labor and labor unions aimed at persuading them to accept, if not actively support, technological changes in the manufacturing and service sectors.

The workshop synthesis paper focuses intently on the operation of the innovation system—it is an inward look. A parallel view from the outside, from "the economy" so to speak, is presently in "Technical Advance and Economic Growth: Present Problems and Policy Issues." This paper analyzes the causes of some of the aspects of present economic difficulties reflected in inflation, unemployment, and declining productivity growth. It concludes that the significant deceleration since 1973 in R. & D. expenditures has been primarily due to the deceleration in growth of economic output. However, slow and conservative technical advance can make it more difficult to get out of the current economic rut, while faster and more innovative technical advance may make it easier to get out. The author does not advocate government stimulus of basic technology as the most important instrument in resolving today's macroeconomic problems, but argues that such policies can be important parts of an effective policy package.

For a different synthesis of much that has been said above, placed in balanced perspective both in terms of time and the international milieu, one last "status report" is offered. "The Revival of Enterprise," by Theodore J. Gordon was presented as a Mitchell Prize Award paper at the Third Biennial Woodlands Conference on Growth Policy in Houston, Texas, October 28–31, 1979. The author defines "enterprise" as "the willingness to venture on bold, hard, and important undertakings with energy and initiative." Production and innovation are two key concepts threaded throughout the paper. He declares that currently in the United States, enterprise "has a strangely negative pall." The paper responds to a set of author posed questions: Was enterprise as real as we remember? Has it really changed? If so, why? Can it be revitalized? Should it be? Gordon's answers are clear and succinct:

> Yes, enterprise did once flourish in our country and has now diminished in intensity. The reasons for its current lack of vigor are hard to pin down exactly, but include satiation, diversion of resources from "productive" to "unproductive" pursuits, and above all, increased uncertainty occasioned by inflation and regulation. Uncertainty results in a short-term perspective. There are many proposals for stimulating innovation and productivity but their effectiveness is not certain, by any means. Even if these proposals work as intended and they stimulate innovation productivity, they may not rekindle enterprise. After all, innovation may be channeled to trivial pursuits and our definition of enterprise requires hard, bold, and important action. Finally, the opportunities and needs for enterprise abound and in some instances, at least, there seem to be few alternatives.

Another paper in the RIAS is on "The Role of Imbedded Technology in the Industrial Innovation Process." Roughly defined, imbedded technology focuses on that great bulk of minute incremental technological changes and advances that constantly occur in all manufacturing, maintenance and operational activities throughout the technological infrastructure of an industrial society. This has been termed imbedded technology or "IT," and concerns a multitude of tiny advances not directly resulting from planned R. & D. efforts. A key part of the effort was to define imbedded technology, and to describe its nature and extent with particular emphasis on its critical, but often unrecognized role in innovation.

One of the problems in analyzing and assessing policy for innovation is clasifying the technuogy and/or its applications in consistent and measurable ways. One aproach to the problem is offered in an exploratory paper, "A Quantitative Technology Index to Aid in Forming National Technology Policy." This paper attempts to go beyond the widely used but vague terms, "high" and "low" technology, to provide an extended and more replicable method of categorizing technology for policymaking purposes. The index proposed is composed of multiple subjective scales in three descriptive areas: the technological product per se, the process of its manufacture, and the nature and extent of the distribution system. As with the other commissioned papers, this is a "think piece" outlining concepts and approaches but stopping short of development of a working tool. If a continuing need is perceived and if this approach appears to have merit, a subsequent action could be to initiate development and testing of the approach offered.

Most of the attention of the literature and current discussion is directed toward our American, large scale, very sophisticated style of innovation. This is perhaps as it should be, for therein has lain the major effort and resource commitment, the largest benefits, and the most critical policy and procedural questions of the past. The paper, entitled "The Role of Small-Scale Technology in Innovation," deals with an innovation issue just emerging on the American scene—innovation for small-scale, decentralized , low energy, low pollution, and possibly more labor intensive technologies and processes. As yet we are unaware of the full nature and extent of this area and thus of its policy implications. This paper will supply a view of this parallel and future oriented countertrend that must be dealt with along with the larger primary issues. As economic, social, environmental, and cultural standards have changed, new and different demands are being made by the public. In recognition of this, innovation in small-scale technology is becoming a part of the U.S. scientific and technological endeavor.

Small-scale technologies are generally labor-intensive, use local materials, are easy to maintain and repair, require minimal capital investment to acquire and operate, and utilize renewable or abundant resources. These technologies also tend to foster self-reliance and decentralized decisionmaking. They offer an alternative mechanism to reach an objective or meet a demand. In pursuit of economic growth a balanced approach to both standard and small-scale innovation is necessary. Innovation in small-scale technology offers a different perspective on the process of invention but it does not preclude nor deny the importance of traditional practices. It is a way or reacting to the increased demand for understandable technology, for technology over which the individual has control, and for technology which reflects individual needs and the requirements of the local environment. By expanding the type of technologies available through innovation, it may be possible to increase the store of technologies from which to select and meet the demands of our changing society.

Another emerging topic is "Innovation in Public Technology." A more accurate title for this exploratory paper might be "the lack of innovation in the (so-called) public technology area." Public demands and Federal regulations are placing increasing responsibilities on State and local governments. Concurrently, budget limitations are constraining the amount of resources that these jurisdictions can spend meeting the needs of their citizens. One solution to this dilemma is to increase the productivity and effectiveness of public goods and services through the application and utilization of technology. This process—labeled "public technology" in the State and local sector—affords a mechanism to foster new innovation to supply solutions to State and local problems. However, non-Federal jurisdictions generally appear to be unreceptive to innovation. Compounding this situation, the State and local marketplace is characterized by a proliferation of policies, practices, and organizations which, when combined with an apparent lack of technical expertise, leads to a "no-risk" environment. Because of the absence of an aggregated market, industry has tended to avoid participation in the public technology venture. The private sector remains apparently unconvinced that there would be a sufficient return on investment in technology specifically designed to meet the needs of these jurisdictions. To fill the gap between what States and localities need and what technological solutions are available, the Federal Government has created various technology transfer and technical capability building programs. Yet it appears that industry could be attracted to innovation in the State and local arena if markets could be identified and aggregated. This would encourage industry competition for new technological innovations to assist State and local governments in meeting the needs of their constituents. The Congress, while interested in innovation, has not devoted extensive attention to the impact of the public technology market on the U.S. economic situation. Among the options available, Congress can provide technology transfer guidelines and support executive branch efforts to improve the technical capabilities of States and localities such that these jurisdictions can offer an additional outlet for innovation in industry.

Outlook and Parallel Innovation Studies

Relating to the past and emerging from the present are a mix of future issues and opportunities relating to science and technology. A central paper in this Research and Innovation portion of the long range oriented SSEC is, therefore, "A Science and Technology Outlook." Covering a period starting about five years in the future, this outlook goes out three decades, with the emphasis on the 15 year middle zone, i.e., 1995. The Outlook identifies those factors internal and external to science and technology (S and T) that need to be understood by policymakers to integrate S and T policy effectively into the overall techno-economic policies of the Government. In one sense, this longer range Outlook in RIAS picks up where the executive branch Science and Technology Five Year Outlook ends. The shorter range effort was mandated by the National Science and Technology Policy Organization and Priorities Act of 1976 (Public Law 94–282). Their initial study is an attempt to set forth a preliminary structure for a comprehensive Science and Technology Outlook, particularly as science and technology relate to economic change.

The approach in this S and T Outlook is fivefold. First, it examines the systemic factors involved in the Nation's scientific, technical, economic, environmental, social and political areas. Second, it investigates the total interactive "environment" in which the national science and technology system operates. Third, it identifies some emerging technological developments which seem likely to be particularly important in the near-term future. Fourth, it reviews basic assumptions, an often neglected task in policy analysis. Lastly, it analyzes the preliminary findings for options and policy alternatives.

Considering basic assumptions first—three scenarios incorporating alternative sets of basic assumptions are developed. The "extrapolative" scenario now seems to be the most likely and most preferable of the three presented in this analysis, although it includes significant existing and emerging problems. Hence, national science and technology policy alternatives are likely to be developed around this basic scenario, or a similar one, either implicitly or explicitly. The thrust of the extrapolative scenario is that the principal parameters of the global (or, at least, American) socio-politico-techno-economic system will remain fairly constant over the immediate and near-term future, that is, for at least the next 30 or so years. Another way of saying this is that the future will be mainly characterized by extrapolations of existing trends. Two alternative scenarios considered for comparison are the "changing values" and "discontinuity" scenarios.

Assuming the general validity of the extrapolative scenario, the national science and technology system may be called upon to contribute, in a global context, to the solution of most, if not all, of the 14 major world problem areas discussed in the report. In the activistic, dynamic society envisioned in the extrapolative scenarios, none of these 14 major world problem areas is likely to be ignored and the following ones are likely to be emphasized:

World population growth and aging populations.
Food: agricultural production and distribution.
Foreign affairs and military security.
Techno-economic security and viability.
Energy.
Health and biosciences.

Likewise, under an extrapolative scenario, all of the ten representative emerging technological developments discussed in the report, and many more, are likely to receive increasing attention and programmatic support from both industry and Government. The ten technological developments discussed are:

Birth control.
Food: agriculture.
Health: combating future cancers.
Biosciences and bioethics: DNA.
Microelectronics: computers and telecommunications.
Transportation: short-hop STOL airliners.
Technology-abetted political participatory systems.
Energy: oil shale.
Energy: fushion.
Space colonization.

Finally, under an extrapolative scenario, two organization policy alternatives are likely to receive increasing attention at the Federal policymaking level. These are:

Further development of the Federal science and technology policy and management structures; and

Further development, and perhaps institutionalization, of the Nation's analytical foresight capabilities and of effective linkages between those capabilities and technology policymakers.

To investigate these factors comprehensively, thoroughly, and continuously probably would require the institutionalization of the Science and Technology Outlook at the Federal policymaking level.

As part of his Outlook, a number of recent studies of the future of science and technology, or of some selected aspects of the future of science and technology, were reviewed for methodology (or approach) and content. A principal example of one such science and technology outlook study is "Science and Technology: A Five-Year Outlook" prepared by the National Academy of Sciences (NAS) under contract to the National Science Foundation. The NSF had been delegated the task originally mandated to the Office of Science and Technology Policy, Organization, and Priorities Act of 1976 (P.L. 94–282). This NAS report uses a "selective approach) and investigates a few areas of science and technology; demography, health, and environment as related to science and technology; and relevant institutions. Other forward looking science and technology reports reviewed include those of the Organization for Economic Co-operation and Development (OECD) project called "Interfutures" and entitled "Facing the Future", for example, analyzed "simultaneously the longer-term problems of the developed countries . . . and relations between these countries and the developing countries." Moreover, the study attempted to consider how governments of developed (particularly OECD) countries could incorporate their short-range activities into longer-term approaches and governmental policy options to address these long-range problems.

Also a number of studies undertaken on an individual basis by several foreign countries were examined. Although not directly related to industrial innovation, readers should be aware of the "Global 2000 Report to the President" which covers the "probable changes in the world's population, natural resources, and environment through the end of the century" and was designed to serve the Administration as "the foundation of our longer-term planning." Similarly, attention should be given to the report of the President's Commission for a National Agenda for the Eighties scheduled for submission in December 1980.

Many private groups and government agencies have studied the multiple facets of industrial innovation, productivity, and science and technology during the same period. In addition, the Carter Administration has issued pronouncements and initiated programs supportive of basic research and industrial innovation. In considering the next policy, action, or analytical steps, readers should at least be aware of the selected and briefly annotated list of documents that follows in appendixes A and B.

Appendix A

Excerpts From Two Decades of Research on Innovation

This appendix reproduces selected material from each of the 42 studies included in the chapter "Two Decades of Research on Innovation: Selected Studies of Current Relevance." The material is presented in the form of selected excerpts of the executive summaries, principal findings, recommendations and conclusions, or other pertinent sections. These selected excerpts, reproduced from the primary sources, permit the reader to view them directly since in many cases it is no longer possible to locate the original documents. Permission to reproduce the material has been given to the Congressional Research Service, Library of Congress, except as noted otherwise.

1. **Little, Arthur D., Inc. and Industrial Research Institute, Inc. Barriers to Innovation in Industry. Executive Summary. Washington, 1973. Prepared for the National Science Foundation under contracts NSF–C748 and C725. 38 pp.**

Abstract

The purpose of this study was to identify and examine barriers to technological innovation in industry and to suggest public policy options for overcoming these barriers. Industrialists, financial managers, government officials, labor leaders, and academicians were interviewed to solicit facts, experiences, and informed judgments. It is their perceptions of both barriers and policy options that were sought and are reported here.

This research indicates that the perceived barriers relate primarily to marketing. Other important barriers concern finance, organizational problems within corporations, lack of seed capital for starting new high-technology businesses, and governmental policies and practices, e.g., in patent, antitrust, and regulatory matters. It was not intended, and no attempt was made, to consider major technical breakthroughs; relatedly, technological barriers are not perceived by industry as significant in the "normal" innovations that it pursues.

The sample of industrial firms were so chosen, for this research, as to cover a spectrum of industry sectors and corporate characteristics with significant variations in such factors as R&D investment, growth rate, capital intensity, product/process obsolescence, and management practices. Interviews were both structured with respect to specific categories of barriers to innovation in order to derive a quantitative rating severity of specific barrier factors, as well as unstructured so as to elicit qualitative perceptions of barrier factor characteristics and suggestions for public policy options to overcome barriers.

Many of the significant barriers can probably be overcome or reduced in importance by suitable public policies. Recommendations were made by respondents in industry, government, finance, and labor for specific public policy options relative to the most significant barriers. Their chief overall comments—in the context of enhancing the industrial environment for innovation—are:

- Designate a focal point in the Executive Branch of the Federal Government to coordinate public policies related to technological innovation.
- Clarify public policy objectives for technological innovation, e.g., international trade, productivity, consumer satisfaction, job creation, increased industrial competition.
- Increase effectiveness of public policies by targeting them to be industry-sector specific where necessary.
- Articulate and aggregate market demand for products and services purchased with government funds, so as to create additional market "pull" (to complement technology "push") in those areas where private market forces are insufficient to sustain innovation.

This study was intended to be an exploratory assessment of barriers to innovation as these are perceived by both the private and the public sectors. The findings are indicative of the relative severity of different kinds of barriers; they are not conclusive evidence in sufficient detail to provide the basis for definitive public policy formulation. Rather, the indicative findings presented (both quantitative and qualitative) of perceptions held in the private sector, together with the suggestions for public policy options that were offered by individuals interviewed, merit consideration by those in government who have the responsibility for experimenting with and developing policies that would provide incentives for technological innovation. In many instances, it is likely that more detailed analyses of specific barriers should precede the conduct of experiments that are to illuminate the efficacy of specific public policy options.

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2. Battelle-Columbus Laboratories. Interactions of Science and Technology in the Innovative Process. Final Report. Columbus, Ohio, 1973. Prepared for the National Science Foundation under contract NSF-C667. Various pagings.

Analysis and Conclusions

This section presents some details of the analyses that were explained briefly in the Introduction and Overview, and summarizes the conclusions drawn from these analyses.

The 21 Factors and the Decisive Events

As explained earlier, 21 factors of probable importance to the direction and rate of the innovative process were selected from the general literature. These factors were rated as to degree of importance to each of the decisive events of the 10 innovations. The factors are defined or illustrated briefly below.

The first three factors are related to various motivational influences:

Recognition of scientific opportunity.—Motivation for the timely acquisition of new fundamental knowledge.

Recognition of technical opportunity.—Motivation for the timely improvement of an existing product or process.

Recognition of the need.—Motivation for solving the problem or meeting the need satisfied by the eventual innovation.

The next four factors involve actions taken consciously by management:

Management venture decision.—Decision by an organization to invest in some large-scale technical activity. The activity need not be directly related to the innovation under study. The decision is usually followed by the formation of an R&D team to carry out the activity.

Availability of funding.—The existence (rather than the extent) of financial support. Early in the innovative process, even limited funds can provide for critical experiments that may influence management decisions.

Internal R&D management.—Role of supervisors and other management personnel within the performing organization. It includes those who give specific suggestions and directions to R&D personnel, set goals and schedules, and assign staff.

Formal Market Analysis.—Economic feasibility studies of an innovation, especially estimates of its potential market.

The next four factors may involve management in some sense, but do not necessarily imply specific action by management:

Prior Demonstration of Technical Feasibility.—Earlier activities that established the practicability of further development or the utility of further research.

Technological Gatekeeper.—An individual who identifies scientific or technical information of relevance to the interests and activities of the researchers.

Technical Entrepreneur.—An individual within the performing organization who champions a scientific or technical activity; he is sometimes also called a "product champion".

Patent/License Considerations.—Existence of patent protection of inventions, or of licensing arrangements.

The next four factors describe peer-group forces that impinge on the R&D scientist:

Technology Interest Group.—(also known as the "invisible college") a group of researchers from different institutions who exchange ideas and findings via personal meetings, letters, etc., as distinct from the formal (publication) channels of communication.

In-House Colleagues.—technical personnel within the performing institution who collaborate on or otherwise facilitate the activity. Often they are members of an R&D team.

External Direction of R&D Personnel.—suggestion of goals and approaches by persons outside the performing organization.

Competitive pressures.—competition among persons and organizations working in the same technical area.

The next two factors are circumstances that are usually unplanned or accidental:

Serendipity.—emergence, during the event, of unexpected scientific or technical results that proved useful in promoting the innovation.

Technology confluence.—merging of major channels of development, often from diverse scientific fields, making possible new advances.

The remaining four factors refer to external factors that form the general environment within which the innovative process takes place:

General Economic Factors.—such as a recession or depression.

Social Factors.—such as group customs, beliefs, and attitudes.

Political Factors.—such as elections or war.

Health and Environmental Factors.—such as famine or disease.

The last four factors permit consideration of influences not included in specific external factors such as, for example, Competitive Pressures. These categories were purposely left broad, so that the appropriate factor could be applied to a given event from among the diverse possibilities.

TABLE 1.—*Percentage of decisive events rated moderately or highly important for each factor*

Factors:	*Percentage of decisive events*
Recognition of technical opportunity	87
Recognition of the need	69
Internal R. & D. management	66
Management venture decision	62
Availability of funding	62
Technical entrepreneur	56
In-house colleagues	51
Prior demonstration of feasibility	49
Patent/license considerations	47
Recognition of scientific opportunity	43
Technology confluence	36
Technological gatekeeper	30
Technology interest group	29
Competitive pressures	25
External direction to R. & D. personnel	16
General economic factors	16
Health and environmental factors	15
Serendipity	12
Formal market analysis	[1] 17
Political factors	5
Social factors	4

[1] In retrospect, one might argue that Formal Market Analysis was bound to be rated low, because such an analysis usually is done only once, and does not continue through the innovative period. But the same argument might apply to Management Venture Decision, which ranks high.

Conclusions About the Factors

No factor was judged important for every event, and yet each of the factors was of some importance to more than one event. For each factor listed, Table 1 presents, in descending order, the percentage of all decisive events for which that factor was judged moderately or highly important. Further statistical analyses of the factor rating yielded an order only slightly different from that of Table 1, and do not affect the conclusions listed below:

Ranking at the very top is Recognition of Technical Opportunity. In other words, the opportunity to attain a technological improvement is a very strong force in the development of an innovation.

Ranking second is Recognition of the Need, which is closely akin to what is sometimes called "market pull". Other studies of innovation have found that innovations most frequently respond to the force of market pull. Our study confirms this observation, as it relates to individual decisive events.

Technical Entrepreneur ranks sixth, and considerably higher than Technological Gatekeeper. Since these concepts are often discussed in the innovation literature, the relative rating of these two factors is especially worthy of note. One might surmise that the Technological Gatekeeper, because of his supposedly more intimate and continuing relationship with the R&D team, would be more important for individual events that the Technical Entrepreneur, but the data show otherwise.

The general external factors—General Economic Factors, Health and Environmental Factors, Political Factors, and Social Factors—rank at the bottom. However, this conclusion bears on the effect of the factors on the individual decisive events, and is not applicable to the innovative process as a whole.

Generalizations from the Case Histories

Table 2 lists eight important characteristics frequently observed and reported in previous studies of the innovative process. Each of the ten innovations was examined for these characteristics. In Table 3, which summarizes the results, "X" indicates that the characteristic was important, and "—" that it was not important to the innovation. The eight characteristics were found in most of the ten innovations, although the independent inventor was found in only three. The following conclusions may be drawn:

The technical entrepreneur, whose importance was highlighted in the study of the "factors", is also a "characteristic" important in nine of the ten innovations. This is the strongest conclusion that emerges from the study.

In fact, in three innovations, the technical entrepreneur persisted in the face of the inhibiting effect of an unfavorable market analysis. If any suggestion were to be made as to what should be done to promote innovation, it would be to find—if one can!—technical entrepreneurs.

Early recognition of the need appeared in nine of the innovations. This confirms the high rating for the corresponding factor in the analysis of the decisive events, and substantiates the importance attributed to "market pull" in other studies.

TABLE 2.—*Some previously reported characteristics of the innovative process*

1. *Early Recognition of Need.*—Recognition of the need for the innovation generally occurs prior to the availability of the technological means for satisfying the need.

2. *Independent Inventor.*—The independent inventor, working on his own behalf, is often important in the initiation of the process.

3. *Technical Entrepreneur.*—The technical entrepreneur is often important to the successful culmination of the innovation.

4. *External Invention.*—Many innovations arise from inventions which originate outside the organization that developed the innovation.

5. *Government Financing.*—Government financing is important in many innovations.

6. *Informal Transfer of Knowledge.*—Innovations are facilitated by informal transfer of knowledge, much more than through formal channels of communication.

7. *Supporting Inventions.*—Innovations generally require additional supporting inventions beyond the initiating invention.

8. *Unplanned Confluence of Technology.*—The innovative process is frequently facilitated by an unplanned confluence of technology.

Adequate funding emerges as an important consideration, both from the study of the case histories and the study of the decisive events. In Table 3, only Government sources of funding are considered. Seven of the innovations had Government support, although this support was limited for one of them. Furthermore, in Table 1, where we consider all sources of funds, Availability of Funding ranks near the top.

The situation with respect to confluence of technology is especially interesting. Table 3 shows that an unplanned confluence of technology was important to six of the innovations. But confluence of technology was present for the other four innovations as well, although it came about from deliberate planning, rather than accident. For the three innovations of improved grains, technology confluence occurred because agricultural science is itself an interdisciplinary field, and has long been supported on that basis. The remaining innovation, Organophosphorus Insecticides, made use of a deliberately formed interdisciplinary team. Technology Confluence also ranks near the middle (Table 1) as a factor influencing the decisive events. The lesson to be learned here is that the benefits of technology confluence should not be left to accident, but should be promoted through deliberate interdisciplinary research.

TABLE 3.—CHARACTERISTICS OF THE INNOVATIVE PROCESS

[Indicated as important (X) or unimportant (—) for each innovation]

Characteristic / Innovation	Early recognition of need	Independent inventor	Technical entrepreneur	External invention	Government financing	Informal transfer of knowledge	Supporting inventions	Unplanned confluence of technology
Heart pacemaker	X	X	X	X	— X	X	X	—
Hybrid corn	—	—	X	X	X	X	X	—
Hybrid small grains	X	—	—	X	X	X	X	—
Green Revolution wheat	X	—	X	—	X	X	X	X
Electrophotography	X	X	X	X	—[1]	X	X	X
Input-output economic analysis.	X	X	X	X	X	X	X	X
Organophosphorus insecticides.	X	—	X	X[2]	X	X	X	—
Oral contraceptives	X	—	X	X	—	X	X	X
Magnetic ferrites	X	—	X	—	X	X	X	X
Video tape recorder	X	—	X	X	—	—	X	X

[1] But limited Government funds were provided to a related development, giving indirect aid.

[2] "External invention" occurred only because World War II enabled American Cyanamid to market the innovation in advance of I. G. Farben.

Analysis and Classification of the Significant Events

In summary of the analysis and classification of the significant events, we may draw the following conclusions:

The time span from first conception to first realization is not growing shorter, as far as can be judged from our limited sample, and in contrast to widely held ideas. This time span averages about 19 years and ranges from 6 to 32 years for the ten innovations studied. The difference in duration between the longest and the shortest is caused mainly by a difference in availability of technology for the two innovations.

In the preconception and innovative periods, MOR and development events become more dominant as time progresses, although NMOR events are found up to and beyond the date of first realization. Such late NMOR events usually represent a process of feedback and diffusion from technology to science.

Can Innovation Be Managed?

Consideration of the conclusions reached from analysis of the decisive events, from the characteristics of the case histories, and from the classification of the significant events, leads one to some conjectures about managing innovation.

There has always been argument about the extent to which research and development can be managed. Whatever may be the merits of differing positions in this argument, we may confidently assert that, in the spectrum of science and technology, NMOR is the most difficult to manage, if it can be managed at all. Furthermore, as we have seen, significant NMOR events continue to occur up to the end of the innovative process; hence, we are forced to conclude that innovation cannot be completely controlled or programmed. Also, the actions of the technical entrepreneur, or the role of such motivational forces as recognition of need and recognition of technical opportunity, involve inventive or creative activities that do not lend themselves to detailed planning. Hence the high ranking of these factors in the analysis supports further the conclusion that innovation cannot be fully planned. We are therefore led to recommend that management, in trying to promote innovation, permit and encourage the opportunity to act upon ideas that fall outside the established or recognized pattern.

But if innovation cannot be fully controlled, we nevertheless can discern ways in which management can help it along. Our analysis reveals two such ways by demonstrating the importance of funding and of the confluence of technology. As to funding, it need not be munificent, at least in the early stages. It not only permits R&D to proceed, but probably also aids the innovative process by the confidence management generates in the R&D team through financial support. As to confluence of technology, it seems almost essential to innovation. Yet it too often occurs without planning, and one suspects that here is an opportunity for management, by promoting interdisciplinary R&D teams, to accelerate the innovative process.

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3. **Boretsky, Michael. Trends in U.S. Technology: A Political Economist's View. American Scientist, v. 63, Jan./Feb. 1975 : 70–82.**

Until the Civil War, the United States was what we would now call an underdeveloped country, and its technology, with few exceptions, was no more than a poor offset rendition of that of Europe. Abundant natural resources, however, coupled with Alexander Hamilton's policy of industrialization, which was vigorously pursued from the time of the Revolution until about the end of World War II, plus an otherwise positive attitude toward technological and industrial development on the part of government and society at large, soon made the United States a rapidly developing country. The most relevant historical evidence suggests that American technology reached parity with Europe by 1870 or thereabout; by the turn of the century, it was in most respects higher than Europe's; and by the end of World War II it had become a literal "wonder" to the rest of the world. Parallel with this technological development, and because of it, America became the greatest world power—economically, politically, and militarily.

Toward the end of the 1960s, and especially since 1971, however, a number of societal attitudes toward technology, on one hand, and quite a few unfavorable economic trends implying similarly unfavorable trends in technology, on the other, have induced considerable speculation about America's economic and political future. The present concern is not with the country's technology relevant to defense and the conquest of space, which occupied the last two decades, but with technology relevant to the quality of life in society at large, as well as, more specifically, productivity and commercial markets at home and abroad.

The debate in question has been underway for some three years or so, but there is still considerable confusion as to the real state of affairs in U.S. technology, and an almost unbelievable amount of confusion as to what precisely the problems are, the reasons for these problems, and what can and should be done about them. There are people who argue that the country's rate of technological progress is heading downward, that our technological leadership in the world is rapidly disappearing, and that in technological prowess, they predict, the United States will become "just another industrialized country" in a matter of a few years.

Others would seem to hold the opposite view: There is absolutely nothing wrong with U.S. technology. To "prove" this theory, they invariably cite the fact that Japan, all European countries, and Canada have been buying and otherwise importing U.S. technology en masse, and that more recently the U.S.S.R. has started doing the same. If there were something wrong with U.S. technology, they contend, foreign countries would not buy it.

There are still others who argue that even if the United States were losing technological preeminence, there is nothing to worry about because (1) the trend is probably inevitable and, to some degree, desirable, (2) U.S. technology is so much more advanced than that of other countries that it will take quite some time for them to approach the U.S. level, and (3) the U.S. economy has strengths other than technology. In an attempt to resolve these conflicting viewpoints and to assess just where the United States stands and seems headed on the technological tote board of comparative economic advantage, I shall try to give a brief analysis of facts bearing on the current state of U.S. technology, the problems to be faced, and the apparent causes of these problems.

In conclusion, I think my analysis makes it unmistakably clear that the choice of solution to the problems the United States faces in technology could radically change the country's socio-economic system and the course of its history. Continuation of current trends would lead, on the international front, to a decline in its economic and political position, pressure on the external value of the dollar resulting in periodic formal or informal devaluations, and the gradual worsening of its terms of trade, causing a lowering of the standard of living. On the domestic front, these trends would result in a continued lag in productivity growth, mounting inflationary pressures, lasting high interest rates, pressures for the redistribution of income, and lagging improvements or even a decline in the present level of the quality of life.

Obviously these conclusions have rather pressing policy implications, but to discuss them here would take this paper beyond its intended compass. Readers interested in reviewing proposals to avert the continuation of the outlined trends might wish to consult another paper of mine which discusses such policy needs and some of the available options in considerable detail.

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4. Boretsky, Michael. U.S. Technology: Trends and Policy Issues. Washington, The George Washington University Program of Policy Studies in Science and Technology, 1973. 174 pp. (Monograph No. 17)

POLICY NEEDS

The preceding discussion might have made it appear that the only thing that the United States needs to cope with the trends in question is more R & D. As far as I am concerned, this is not so. More economically and "quality-of-life" oriented R & D is an important element of U.S. needs, but it is far from everything. In my judgment, what the United States needs (please note I am addressing myself here to the *needs*, not *options*) is a *comprehensive national technological policy*. In broad terms, I define such a policy simply as *the sum of deliberate actions on the part of Government aimed at the increase and improvement of technological options and alternatives for all productive units in the economy for the furtherance of national objectives within the constraints of available and/or accessible resources.*

At this time, there are bits and/or pieces that might fall into the scope of this definition, but the country does not have a coherent policy per se. As I see it, the institution of such a coherent policy, in the conditions of the kind of market economy and Governmental institutions as we have today, would have a dozen or so strategic elements. These would have to include:

(1) Intelligent planning and continuous review of the country's level of effort in the enhancement of technological development by major processes and sectors of the economy.

(2) Development and institution of policy measures assuring an optimum supply of appropriately trained scientific and technological manpower, both as to various educational levels and within each level (including supply of technicians and "craftsmen"), consistent with the country's prospective (long-term) level of effort in technological development.

(3) Development and institution of general and meaningful (effective) incentives for an optimum level of private investment in R & D.

(4) Securing an optimum public investment in R & D in social infrastructure, including those relevant for society's "quality-of-life," and in civilian-market-oriented technological opportunities where for various reasons (such as industry fragmentation, excessive risk, etc.) the market forces and general incentives cannot assure an optimum level of effort.

(5) Securing the proper industrial environment for the optimum utilization of new technology of domestic and foreign origin.

(6) Securing the proper Governmental legal and regulatory posture with respect to the development and utilization of new technology.

(7) Development and institution of patent policy that would tend to optimally stimulate the strive for development of new technology rather than to hinder it.

(8) A Governmental procurement policy that would be conducive to the diffusion of new technology.

(9) Development and institution of policies that would assure optimum benefits of the country's technological effort for foreign trade and the balance of payments.

(10) Development of adequate and rationale safeguards against the ill use of new technology without stifling controls.

(11) Institution of a system of "enlightened" timely publications which would inform the public about the social consequences of major technological changes—both beneficial and not so beneficial—and the available alternatives.

(12) Finally, there must be an institutional focal point of continuous responsibility within the executive branch of U.S. Government for the state of technology in the economy at large, statutorily empowered to initiate new policies as well as changes in old policies which became either inconsistent with the Nation's needs or do not work effectively.

I should like also to note that, in contrast to the United States, all other major industrialized countries have by now at least some sort of central point and continuity of Governmental responsibility for the state of technology in their economies at large, and most of them are quite elaborate and, evidently, quite effective. In short, by now the United States has an "entirely different world" to cope with than it used to have.

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5. Cunningham, Donald E., John R. Craig, and Theodore W. Schlie, eds. Technological Innovation: the Experimental R&D Incentives Program. Boulder, Colo, Westview Press, 1977. 505 pp.

Background to the Experimental R. & D. Incentives Program

(By Donald E. Cunningham, John Craig, and Theodore W. Schlie)

This book presents results from the first three years of the National Science Foundation Experimental Research and Development Incentives Program (RDI). The material is being made available to the academic, industrial, and governmental communities more in the sense of exploring a range of alternatives for governmental intervention rather than in analyzing the results of possible interventions. The papers presented are program-planning documents rather than results of actual experiments. The papers do not attempt to represent complete coverage of the program, but only to indicate the scope of the investigations. Abstracts of additional studies and reports appear at the end of the book. In spite of efforts by the U.S. Government to publish and abstract reports and results of the studies that it sponsors, much useful work exists only in fragmented form with no unifying themes to tie it together. The selected papers in this book will bring together the various documentary outputs of a program into a consolidated and usable form that represents much of the recent thinking on technological innovation.

To put RDI in perspective, a brief history of its origins is helpful. The socioeconomic situation in the United States in the early 1970s was much different than it is today. In some ways it was simpler, since the Arab oil embargo and price increases had not yet taken place. In other ways, however, complex questions concerning the relationships between science and technology, innovation, the economy, the environment, and the society in which we live were already being asked.

A major question—never satisfactorily resolved—which impinged on the deliberations that occurred was the appropriate role for U.S. federal intervention in the technological innovation process. In the areas of national defense, space, and atomic energy, of course, the federal government had for some time played a major—if not exclusive—role by intervening in ways such as direct and indirect subsidies to high-technology industries, the operation of its own federal laboratories, and loan guarantees to failing aerospace companies. Increasing questions about the availability of risk capital for innovative products and processes, the decreasing productivity of U.S. industry balance-of-payments deficits, unemployment, the growing service sector of the national economy, increasing demands for social services, the plight of our cities, and the newly emerging life style summed up in the concern for "quality of life" all demanded some federal response.

RDA was proposed to provide a national R&D assessment capability—to carry out and to support research, studies, analyses: "The goal of this proposed new program is to achieve a fuller understanding of the R and D and innovation systems and how they may better contribute to national goals and objectives." [2] RDA originally focused its efforts in eight areas:

1. Analysis of data on national R&D trends and forecasting.
2. Analysis of the processes of invention, innovation, and diffusion of new technologies.
3. The public and private rates of return from R&D, and how R&D is related to more efficient utilization of resources, employment opportunities, productivity, and foreign trade balance.
4. The role of science and technology in society and its potential contributions, costs, and relationships to existing and future institutional structures.
5. Foreign experience in the area of science and technology policy, particularly those countries, such as Japan, which have recently experienced rapid economic growth, to determine implications for United States policies.
6. Multinational efforts at developing policies for R&D (such as the Organization for Economic Cooperation and Development), and the implication of these efforts for the United States.
7. The impact of federal policies through legislation and regulation on the use of science and technology and on the total innovative process in the United States.
8. Analyses of the relative impact of federal and private R&D investments on innovation and economic growth, including an assessment of the results of the new experimental incentives program. [3]

In its official program announcement, RDI stated its objectives very simply: (1) to identify institutional barriers to innovation; and (2) to test appropriate federal action which might reduce such barriers. [4] In earlier program documentation, however, RDI's objectives were more extensively outlined. Specifically, they were:

1. to identify the barriers and stimuli within the innovation processes in selected segments of the domestic public and private markets as well as world-wide markets.
2. to develop an understanding of the causes and effects of the major identified barriers and stimuli.
3. to find the means and relevant incentives to overcome the barriers or to strengthen the stimuli.

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4. to discover the limits of applicability of those means and incentives.
5. to assess the implications of the broad application of those means and incentives in terms of consequences and costs on the quality of life of individual citizens and the progress of the nation as a whole; employment opportunity for all segments of society; and the economy, including the status of the international trade balance and productivity.[3]

Underlying the design of RDI was a set of assumptions which were explicitly stated early in the program planning process:

1. There exists the potential for spawning new innovations in the civilian sector by coupling more effectively R&D resources to needs of the private and public sectors and industrial resources to the needs of the consumer.
2. Many such potential developments are in the best interests of the nation and the participants, and some fraction of this potential is presently going untapped.
3. The federal government can provide incentives which will catalyze the realization of some of this potential in a manner which is cost-effective and socially beneficial from the national viewpoint.[2]

Once established, the RDI program was not large in terms of dollars expended, as shown by $11.5 million spent in fiscal year 1973 and $10.5 million in fiscal year 1974. These dollar amounts dictated the sort of incentives that could be tested. They were necessarily of the high-leverage, non-hardware-oriented type, and this accounts for the shape and content of the program. In developing the program's plan, it became clear that not all incentives and all situations could be examined. In some cases, experimental results would be so diffuse as to be incapable of evaluation given the financial resources available. A plan was therefore drawn up to investigate where the NSF incentives program might effectively proceed. Certain broad categories of effort were delineated. These included:

1. *Investigation and categorization of innovation models.*—This included a look at the model assumptions, steps involved in constructing the model, how and in what regimes the model functions, and general characteristics of technological innovation as exhibited by particular models.
2. *Industrial incentives.*—The structures of particular industrial sectors were to be examined, as were potentials for the technological innovation in specific industrial situations, barriers which might stop innovation from taking place, possible industry-specific federal incentives, and secondary effects which might stem from application of the specific incentives.
3. *Venture capital availability.*—This included investigation of traditional venture capital activities, including existing barriers to increased investment and the means to make technologically-based endeavors more attractive to nontraditional venture capital sources (e.g., banks, insurance companies, unorganized capital, etc.).
4. *Import-export considerations.*—These included identifying situations where a federal intervention might have leverage in enhancing an industry's position internationally with the least negative international side effects, how marketing information might aid U.S. companies, and how U.S. regional profiling might identify capabilities to move into overseas markets.
5. *Regulatory considerations.*—For example, what are the primary and secondary implications of clean air standards, the processes by which standards are derived, and the interactions of various federal agencies in developing and enforcing regulations?
6. *Antitrust, patents, taxes.*—This examined which business sectors are aided by tax incentives and in what ways; how and why antitrust laws are enforced and their effects; and to what industrial sectors are patents important, and why.
7. *Institutional partnerships.*—This examined what situations call for partnership; whether they should be permanent; reasons for failure or success; and characteristics of the partners and the partnerships.
8. *The public sector.*—This examined what is different about the innovation process here as compared with the private sector; the interfaces between public and private sectors; and how inter- or cross-agency incentives might be developed.
9. *Human resources.*—This examined where personnel interchanges have worked and why, and what roles job satisfaction has in the innovation process.

REFERENCES

[1] *President's Message to the Congress on Science and Technology*, 92nd Congress, House Document no. 92–193, March 16, 1972.

[2] Bisplinghoff, Raymond L. "Testimony on Experimental R and D Incentives and R and D Assessment Programs, fiscal year 1973 Authorization before the House of Representatives," February 25, 1972.

[3] Bisplinghoff, Raymond L. "Remarks to the National Space Club," Washington, D.C., July 13, 1972.

[4] National Science Foundation, "Program Announcement—Experimental R and D Incentives Program," Office of the Director, Washington, D.C., November 1972.

[5] Kershaw, David N. "A Negative-Income-Tax Experiment," *Scientific American*, vol. 227, no. 4, October 1972.

[6] Rivlin, Alice M. "Social Experiments: Promise and Problems," *Science* editorial, vol. 183, no. 4120, January 11, 1974. See also Alice M. Rivlin, *Systematic Thinking for Social Action*, Brookings Institution, 1972.

[7] Riecken, Henry W., of the University of Pennsylvania is chairman of this committee. At the 1974 Annual Meeting of AAAS, he presented a paper to the Symposium on Institutions for the Application of Science to Social Needs entitled "Institutions for Social Experimentation."

[8] Campbell, Donald T., and Julian C. Stanley, *Experimental and Quasi-Experimental Designs for Research*. (Chicago: Rand McNally and Co., 1973). In their introductory remarks, they state the following: "By experiment we refer to that portion of research in which variables are manipulated and their effects upon other variables observed. It is well to distinguish the particular role of this chapter. It is *not* a chapter on experimental design in the Fisher tradition, in which an experimenter having complete mastery can schedule treatments and measurements for optimal statistical efficiency, with complexity of design emerging only from that goal of efficiency. Insofar as the designs discussed in the present chapter become complex, it is because of the intransigency of the environment; because, that is, of the experimenter's lack of complete control."

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6. Denison, Edward F. Accounting for United States Economic Growth 1929–1969. Washington, The Brookings Institution, 1974. 373 pp.

SOME CONCLUDING OBSERVATIONS

Growth accounting neither rests upon nor provides any grand general model or general theory of the ultimate reasons for modern economic growth and variations in growth. It does try to provide facts concerning changes in determinants of output and their effects upon output to which such a model or general theory must conform, and against which more limited generalizations may also be tested. Studies for various places and times are gradually bringing an accumulation of such information.

This study has found that changes in only a few of the many determinants of output account for almost all of the growth of the American economy over a forty-year period, and for variations in the growth rate within that time span. They were:

Employment, with account taken of the age and sex of workers entering and leaving employment and of the conventions adopted to measure output in general government, households, and institutions.

Working hours, including the effects of changes in the proportions of part-time workers.

The education of employed persons.

The capital stock, with account taken of practices actually followed in measuring output of dwellings and international assets.

The state of knowledge.

The proportion of labor misallocated (by the criterion of maximum output) to farming and to small and inefficient family enterprises in the nonfarm sector.

The size of markets.

The strength of, and pattern of short-term change in, demand pressures.

The same determinants were found to be largely responsible for growth in European countries, and for differences among nine nations in postwar growth rates—except that recovery from wartime distortions was of clear importance in some countries in the early postwar years.

It is reasonable to suppose that the same determinants will dominate future growth, and that among them will be found the main variables that the United States would need to influence if it wished to adopt a policy of influencing the growth rate in the future.

Yet it must not be supposed that they explain all differences in output. Statistical evidence of this is to be found in international comparisons of levels of output. These determinants—and others whose effects have been measured—can explain only a fraction of the wide margin by which output per person in the United States exceeds that in Western Europe. Other factors—perhaps stronger competition to force efficiency, perhaps better management, perhaps a harder-working labor force, perhaps something else entirely—must account for the remainder. Until the cause of the unexplained output gap can be identified and measured, we can only refer to these factors as "residual efficiency," or the "*x*-factor."

I have not found it possible to deal satisfactorily with quality of management at the statistical level. Strictly speaking, management is merely a type of labor and the quality of management no more requires a separate entry in sources of growth tables than does the quality of any other separate occupational group. But management occupies a peculiarly strategic position in the labor force, and estimates of labor input I am able to construct handle the special qualifications of management very incompletely.

Although I judge that changes in the "miscellaneous" or "n.e.c." components of the classification did not affect growth much in the United States in the time span considered here, this does not mean that they cannot do so or may not do so in the future. Indeed, in Chapter 6 I suggested several determinants that may change adversely and impair future growth. Moreover, most determinants which refer to aspects of misallocation and wasteful or inefficient use of resources fall in this category. In a previous study I examined possibilities for raising the growth rate by improving resource allocation and removing obstacles to efficient production. Although I concluded that the possible additions to future long-term growth that one might hope to secure in this way appear small when measured in perentage points, I also noted that even small gains are worthwhile and that it is in this area that steps to achieve gains in output can be undertaken at the lowest real cost.

Finally, the determinants of output examined in this study may be influenced by many aspects of the American society and economy—by everything that affects birth rates, by the level and structure of taxation, by attitudes toward work and saving, and by government policies that affect incentives, to suggest only a few. But these background conditions exert their influences by affecting determinants of the type examined here, and their effects can be studied only by attempting to appraise which of these determinants they affected, and in which direction and by what amount they did so. Estimates based on a classification like the one used here are therefore necessary for any serious appraisal of the effect of such background conditions.

And so I conclude with the ready admission that this book, comprehensive though it may appear in comparison with most quantitative studies of growth, makes no pretense of dealing with everything that affects growth. That would require encyclopedic presentation not only of almost everything known about the American people and the American economy but of much that has yet to be learned as well.

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7. Freeman, Christopher. The economics of industrial innovation. (Baltimore) Penguin Books (1974). 409 pp. HC79.T4F73.

This textbook provides a thorough review of current economic theories of innovation. Freeman argues that the professionalization of R. & D. has been one of the most important changes in modern industry, and that the requirements for successful innovation have greatly modified firm behavior by making world technology as well as world markets part of the firm's environment. Freeman concludes that market mechanisms have failed in consumer goods/services, and suggests greater public participation in consumer-oriented innovation (copyright permission not granted to reproduce original material).

8. Gilpin, Robert. Technology, Economic Growth, and International Competitiveness. A report prepared for the use of the Subcommittee on Economic Growth of the Joint Economic Committee of the Congress of the United States. Washington, U.S. Govt. Print. Off., 1975. 87 pp. At head of title: 94th Congress, 1st session. Joint Committee Print.

VII. Conclusions

The overall recommendation of this report is that technology policy must be coupled with socio-economic policy. At all levels of policymaking and across the broad spectrum of government activities, technological options and user-needs (or market-demand) must be brought together and integrated in policy-making. Such a recommendation seems self-evident and easy to accomplish. In fact, the coupling of these two aspects of government policy is too seldom achieved. While in theory it is easy to do, in practice it is exceptionally difficult because of institutional commitments and lack of sufficient knowledge.

In order to achieve the goal of coupling technology and our goals, we began by asking what do we know about this coupling process. Throughout this report, we have been examining this question. What remains to be done here is to draw forth the implications for government policy. Beyond this, it is necessary to inquire how this policy can be institutionalized. As suggested above, it is this latter issue which is by far the more difficult one. For this reason, the suggestions made herein are meant to provide the take-off point for discussion rather than a firm set of policy recommendations. First, what is necessary in order to couple economic and technology policies?

The Primacy of Demand-Pull Over Technology-Push

Everything we know about technological innovation points to the fact that user or market demand is the primary determinant of successful innovation. What is important is what consumers or producers need or want rather than the availability of technological options. Technological advance may be the necessary condition for technological innovation and on occasion new technology may create its own demand but in general and in the short-run, the sufficient condition for successful innovation is the structure or nature of demand. This overriding consideration has several critically important implications for government policy.

In the first place, outside the area of basic research, government programs for funding R and D must be coupled with user needs and demands. By "user needs" I mean either the private sector or government agencies seeking to achieve some policy-objective. What we tend to have, however, is a "technology-push" concept of government funding for R and D. Most government programs in the area of scientific research and technological development tend to operate with what can be described as a "technological-fix" philosophy: If we put enough dollars into technology, a solution will somehow be found. If we get the technology, someone will find a way to use it. At the same time elsewhere in the bureaucracy other officials are studying specific problems which require solutions ranging from better methods of garbage collecting to automobile safety. That is to say they are concerned with the needs and demands of society. Yet, too seldom are the two groups—one concerned with technology and the other concerned with user needs—brought together.

The Central Importance of Uncertainty

Undoubtedly the most critical and least appreciated aspect of technological innovation is the problem of uncertainty. As we have seen, technical and economic uncertainty surrounds all innovation and cannot be completely eliminated, though it can be reduced by better management methods, technological assessment, and so forth. It is inherent in all types of innovation—policy or technological. As such, a healthy respect for uncertainty should be the keystone of government policy-making. The overriding consideration in all policy-making involving technological innovation should be the fact that there is so much we simply do not know. This lack of knowledge and the reduction of uncertainty should be the key element in all policy-making.

Specifically, what this means is a more experimental, incremental, and step-by-step approach to policy-making and technological innovation. As this report has emphasized, there are vast unknowns about the ways in which government policy does or could influence innovation, industrial productivity, and the solution of socio-economic problems. For this reason, government policy should seek to reduce these unknowns. Until uncertainty is reduced, government policy should proceed on an incremental and experimental basis. In policy-making it must be recognized that money spent in finding out whether or not something will work is money well spent in the long-run. Any other approach is extremely costly.

The Proper Role of Government R and D Funding

The proper role of government R and D funding should be to complement R and D funding in the private sector; public funds should not become a substitute for private funding. Both are necessary and have their appropriate objectives. In practice, this ideal means two things. In the first place, the government should avoid the funding of commercial development. This is the responsibility of the private sector with its greater capacity to link technology and market demands. In the second place, it does mean that the government should finance scientific research and experimental developments in those areas where it can be established that private industry because of market imperfections tends to underinvest, or because of a divergence between public and private interests industry is failing to meet public needs.

The Question of Institutional Mechanisms

Obviously, organizations and institutional mechanisms are important. There is some merit in all the ones which have been advocated. But the fundamental problem is one of attitudes or philosophy with respect to technological innovation and its role in our economic and political system. It would make little sense, for example, to create a Council of Scientific and Technical Advisers, a National Planning Agency, or a National Institute for Technology unless we transformed our approach to policy-making and technological innovations. What is important is to get people to think in terms of problems or roadblocks needing solution rather than in terms of technology. The need is to couple technology with social and economic needs in order to solve our economic and social problems. The approach to problem-solving and to innovation must be experimental and incremental. The approach must be one of reducing uncertainties, unknowns, and roadblocks which restrict the solution of socio-economic problems and the success of technological innovations.

The need, therefore, is for a new or renovated government agency which would assume the leadership for improving the overall competence of the federal government with respect to micro-economic analysis and policy-making. If a high level agency were to carry out this mandate, it could undertake or support the types of studies and experiments presently being carried out by ETIP. Such an improvement in the government's capacity for micro-economic analysis would not only be a major step forward in its own right but it could go a long way toward the achievement of the major recommendations of this report: the need to couple economic and technology policies.

A National Strategy for Science and Technology

When both the President of Ford Motor Company and the President of the United Automobile Workers advocated national economic planning, the issue of planning and the establishment of national priorities must be taken seriously. For many scientists, engineers, and industrialists, on the other hand, the idea of government planning and priority-setting is anathema. Scientists in particular believe in the right of the scientist to do his own thing; he is among the last of the rugged individuals in this world. Fortunately, or unfortunately, science and technology have become too important to leave to the scientists and engineers.

The issue, however, is not whether the government will or will not set research priorities. It obviously does. A glance at the distribution of R and D funds over the past several decades and the heavy emphasis on "big science and technology" related to defense and prestige clearly indicates what these priorities have been. But we now confront a new set of national problems and require a revised set of national priorities for R and D. The questions we must answer include the following: What should be our R and D priorities? How should they be determined, and by whom? In short, we must confront the issue of priorities for R and D much more consciously and systematically than we have in the past.

In the first place, a national science/technology plan or set of R and D priorities should be in the nature of targets and the setting forth of the direction in which we should move. They should be provisionary and capable of revision in the light of scientific and technological advance. In contrast to the type of planning that characterized the Apollo project (i.e., to land a man on the moon), incrementalism should be the primary characteristic of such a plan. As science, technology, and national objectives change, so must the features of the plan. For this reason, there is undoubtedly merit in the idea that the Council of Science and Technology Advisors submit an annual report to the Congress and the public in order that national R and D priorities can be reviewed and debated publicly.[1] In short, the purpose of the R and D plan and annual report would be to set the agenda for a more conscious and systematic evaluation and discussion of national priorities rather than the establishment of hard and fast objectives.

Secondly, the coupling of technology and "user demand" should take place at all levels including the very highest. Accordingly, the users of science and technology as well as the providers should be represented on the Council of Science and Technology. Scientists and to a lesser extent, technologists, are extremely reluctant to assume the responsibility of establishing priorities among fields of science and technology. Priority setting among disciplines runs counter to the ethos of scientists that all fields are equal and that significant discoveries may come forth from any field. For these several reasons, there may be merit in the idea that the head of a Council of Science and Technology advisors should be a non-technical person and that its membership contain non-scientists/technologists, industrial users, economists, public representatives, etc.

Thirdly, the purpose of government policy should be to support and advance national capabilities in science and technology. On the level of basic and applied research, this means the broad support of university and, where appropriate, industrial as well as in-house government research. The identification of knowledge-gaps and promising opportunities would be a major responsibility of the science and technology policy mechanism. Both the scientific and technical communities could be brought into this effort through panels of experts, special task forces, etc. Beyond its support of basic and applied research, the government should fund experimental development. The identification of important social and economic technologies neglected by the private sector and the stockpiling of "on the shelf" technologies would be a major government responsibility. Unless a powerful case could be made, however, the government should not become involved in the commercial development of technological innovations. The major task of the government in the area of technology is not to supplant private enterprise but to complement it through research and experimental development programs which reduce uncertainty; it should only undertake those tasks which market and other imperfections inhibit industry from doing.

And, fourthly, more government agencies should be encouraged to develop R and D strategies and support basic research, experimental development, and graduate education in universities and schools of engineering. As we have seen, too many government agencies (including Agriculture) tend to concentrate their support on their own laboratories and don't draw sufficiently upon the large reservoir of talent existing in institutions of higher learning. A new alliance must be forged between the agencies responsible for achieving our emerging set of national priorities and the American scientific-technical community. As we have already suggested, a major step in this direction would be taken if ERDA followed the example of NASA and supported a broad program of engineering studies and assumed part of the responsibility for replenishing our most basic resource—the supply of engineers and scientists.

Despite the pressing need for all these measures, this report must conclude on a note of caution. The establishment of research priorities and an emphasis on more planning should be undertaken with a full appreciation of the limitations of such an effort. In the establishment of R and D priorities and the emphasis on planning to integrate economic and technology policy, a potentially serious dan-

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[1] The recent report of the Federal Council could be the beginnings of such an effort. Federal Council for Science and Technology, *Report on the Federal R and D Program*, FY 1976.

ger must be guarded against. Behind the calls for more economic planning in the United States as a response to our many economic problems, one fears there lurks the desire to protect rather than to rejuvenate the American economy. The protection of existing industries and markets rather than the creation of new industries and markets could too easily become the purpose of government policy.

There is a grave danger in the United States today that government decision-making and industry-wide, quasi-cartels could be substituted for the operation of the market mechanism. The temptation to use commercial innovation as a vehicle to supersede the discipline of the market is considerable. Employing an array of arguments—the threat of foreign competition, scale of technology, security of supply, "Capital gap," etc.—the proponents of greater government funding of commercial innovation urge the government to assume the role and risk of entrepreneurship. The proposals to revive the National Recovery Administration (NRA), to subsidize the aerospace industry with public funds, and to put a floor under energy prices to stimulate innovation move in this dangerous direction.

This report has been prepared with a haunting awareness that in arguing that market imperfections may cause underinvestment in innovation and that there is a role for government financing of industrial R and D, it might contribute to unjustifiable government interventions in the private sector. The way in which the argument of this report could be distorted and used to rationalize unwarranted government subsidization of commercial innovation has been well put by Eads:

"The theory of externalities in its simplest form predicts that under a certain set of assumptions there will be a general tendency for private industry to under-invest in technological change and states that federal intervention aimed at correcting this tendency is proper. The practical outcome is that someone—perhaps even a party having a substantial private financial interest in the outcome—perceives that an industry is achieving a rate of technological change below the level that the particular party believes is desirable. After suitable publicity has increased public awareness that a problem exists, a prestigious panel is thereupon convened. After an appropriate interval it produces a report stating that while, of course, everyone knows that the economy would operate best if the market were left free to operate, in the particular case at hand the market has 'failed' and cannot be trusted to bring about the socially desirable result. It is at this point that the theory of externalities is invoked." (Eads, March 1973).

The manner in which we manage the so-called energy crisis will be very instructive with respect to our capacity to rejuvenate our economy in an intelligent way. On the one hand, the resource, environmental, and related problems affecting our economy may very well be the functional equivalent of catastrophe. They can and could force the long-term rebuilding of our technological-industrial infrastructure. New demands and needs have been created which, with proper incentives, could lead to the innovation of new industries and technologies which in turn will generate new technology-intensive exports. On the other hand, in our anxiety to find a quick and short-term solution to our energy and related problems we could, through government subsidization of large and commercially inefficient technologies, harm our economy. In pursuit of energy independence and security of supply, for example, we may lock into our economy a high, non-competitive price of energy.

If we were to move into this direction of subsidizing and protecting inefficient industry we would be following the British rather than the Japanees example. Invoking a variety of rationalization and policy mechanisms, the British have subsidized and protected inefficient firms producing commercial innovations which the market would not accept. The Japanese, on the other hand, have been ruthless in eliminating inefficient firms and have stayed clear of government subsidization of commercial innovation. How unfortunate it would be if the United States in seeking to emulate "Japan Incorporated" fell into the error of "Britain Incorporated" instead.

In conclusion, this report proposes no panacea for the problem with which it began: the relative economic and industrial decline of the United States. What it has sought to do is stress the importance of technological innovation if we are to grow economically, compete internationally, and meet our domestic social needs. Beyond this, it has set forth the direction in which we must move if we are to improve our innovative capacity and use technology for socially and economically beneficial ends.

9. Harbridge House, Inc. Legal Incentives to Private Investment in Technological Innovation. Preliminary final report. Prepared for the Office of Experimental R. & D. Incentives of the National Science Foundation under contract NSF–C893. n.p., 1975. Various pagings.

Draft Evaluation of Incentives: Preliminary Analysis and Ranking

I. Introduction

The preferred incentives listed below in Part III (that is, candidates for further examinations) were identified by analysis of the original submission of 39 in the light of three criteria:

Probable significance to private investment.—What would the incentive really attract private capital? (Private capital, for purposes of this criterion, included not only capital from outside sources, but internally generated funds that the managers of a firm had available for investment.)

Economic leverage.—What leverage does the incentive provide to technology utilization? Will other companies be inclined to jump on the bandwagon of technology favored by the incentive?

Political and legal feasibility.—Does the incentive stand a reasonable chance of being palatable to the executive agencies, the Congress, and the courts at the present time or in the immediately foreseeable future?

The prime standards noted above are, to a considerable extent, condensations or more discriminating criteria (13 in all) set forth in the statement of work for this incentives project. It seemed appropriate to use summary criteria at this point, however, since application of more refined criteria (for example, cost to federal government and ease of communicating and administering the policy option) will depend in some cases on industries selected and the way in which qualification standards are drafted.

As a preliminary step in the development of tentative rankings, we found it useful to categorize all of the incentives by whether or not they required "qualification" or "definition" of an innovation (or innovative industry) and by the financial parameters to which the incentive primarily relates (availability, accessibility, allocability of capital). These groups are explained in Part II which follows. The groups were not directly used in the ranking analysis, but provide a useful framework, we think, for assessing the results of the analysis. These results are contained in Part III. Part IV is a supporting discsusion.

II. Incentive Groupings

A principal basis for classifying the draft incentives is whether they are concerned primarily with the availability, the accessibility, or the allocability of capital:

Availability refers to the general credit environment (that is, the availability of capital in relations to demand for the economy as a whole).

Accessibility looks at the relative ease or difficulty of obtaining or attracting capital within a given general environment; that is, incentive aim to shift the flow of capital rather than increase the total supply.

Allocability refers to investment decisions within the firm or an industry in the context of planning and capital budgeting.

These elements of classification are the bases for three principal groups of incentives below—Groups 2, 3, and 4. Another method of classification is whether or not the incentive proposed requires some type of "qualification" by the recipient or beneficiary. Most of the incentives proposed require some such test. Those that do not are pulled together in Group 1. A few incentives had special features that seemed more significant than either of the above classification schemes, and these have been identified as Groups 5, 6, and 7.

Exhibit I summarizes these groups and indicates the type of qualification required for the different incentives within each group.

GROUP 1: "BROAD GAUGE" INCENTIVES (NO INNOVATION QUALIFICATION)

As indicated above, most of the incentives making up the draft inventory visualized some type of qualification for the incentive to be operative. Thus, a guaranteed loan would be made or a tax credit given for a "qualifying investment"—that is, an investment in technological innovation in a field of some significance to the program.

For several incentives, however, no such qualification test was involved. This group includes proposed changes in certain Securities Exchange Commission rules; in provisions relating to stock options in tax rules related to research and development expenditures, preferred dividends, and Sec. 1244 losses; and in certain antitrust policies.

In many of the above cases the volume of transactions involved would make it administratively awkward to sort out qualifying and nonqualifying situations; the change, if adopted, would be better introduced on an across-the-board basis. Many of these incentives are by their nature limited to small business. Their effect would be to generally improve the small business investment climate without major impact on tax revenues or other sectors of the economy.

One of the proposed changes in antitrust policy (repeal of transportation rate bureau antitrust exemption) must operate across the board, since its aim is to indirectly promote innovation by generally stimulating competition. The other incentive in the antitrust field change in the Department of Justice merger guidelines) in effect introduces the qualification test into the guideline criteria, so it too is appropriately proposed on an across-the-board basis.

GROUP 2: AVAILABILITY INCENTIVES

Two incentives can be regarded as related to capital availability in a general sense: they are designed to improve it by mechanisms that would increase the supply of money and credit. In effect, specified loans to finance innovations made by member banks of the Federal Reserve System would not count in computing lending capacity, or would be rediscounted at full principal amount, with no attendant charge.

With reference to various tax incentives (indirect subsidies), the question is whether they are more appropriately regarded as influencing availability or accessibility. To the extent that they represent government borrowings supported by Federal Reserve purchase of securities (open market operations) they tend to increase the general supply of credit. In other circumstances, the incentives may simply involve a trade-off of one source of revenue for another. Following Professor Stanley Surrey's characterization of the general investment tax credit as a "subsidy of broad scope and high visibility" that can be a "flexible macroeconomic tool," [1] we have placed the investment tax credit incentives, albeit more limited, in this group. Other tax incentives are shown under accessibility.

GROUP 3A: ACCESSIBILITY INCENTIVES

Accessibility incentives are primarily directed to sources of capital outside the firm, to make investment in innovation attractive in relation to other investment channels. Some of the "broad-gauge" incentives in Group 1, of course, were of this type. Those indicated here are ones requiring a qualification or definition of the innovation that is to be financed. There are two subgroups: the first includes incentives that are of principal significance to small or medium firms, while the second contains those of more general application.

GROUP 3A: ACCESSIBILITY TO CAPITAL SOURCES, SMALL AND MEDIUM FIRMS

The proposed tax deduction for equity investors is an indirect means of attracting capital.

Direct means include interest subsidies and loan guarantees for private lenders and SBA innovation loans. Although the latter is not "private investment," it is included here since it can stimulate additional financing from private sources.

The proposed tax credit for equity issue and debt issue costs is placed here, since its function is to make it easier to attract capital through security issues. It also has aspects of allocability (that is, the tax credit reduces costs and thus frees up internal funds for innovation investment), and hence can be regarded as a hybrid. A borderline case is market catastrophe insurance, which we have put here although we have placed innovation market loss insurance in Group 4.

GROUP 3B: ACCESSIBILITY TO CAPITAL SOURCES, GENERAL

Incentives here include the interest rate subsidy for safety compliance, securities litigation indemnity, and state technology investment bonds.

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[1] "Pathways to Tax Reform," p. 206.

GROUP 4: ALLOCABILITY INCENTIVES

This group includes devices to make investment in technological innovation attractive for a firm, as opposed to alternative uses of available capital. The incentives focus on the decision-making process within the firm. Several involve tax deductions or deferrals or other tax changes that would improve earnings or cash flow. Others are in the nature of market assurance policies, such as procurement guarantees or price protection. All proposed incentives require a qualifying innovation (or innovative industry); none are specifically limited to small firms.

GROUP 5: COOPERATIVE ARRANGEMENT AND AGGREGATIONS

Certain incentives visualize a synergistic effect from aggregations (that is, mergers) and/or cooperative effort, such as joint ventures and licensing pools. These incentives primarily affect allocability decisions, although government financing in aid of aggregation can be viewed as relating to accessibility also.

GROUP 6: TECHNICAL ASSISTANCE

The federal/state resource and market assessment incentive may involve loans or grants to small or medium-size firms with a technology orientation. Its distinguishing feature, however, is that it funds state agencies and regional commissions to identify and assist such firms; hence it has been placed in a special category.

GROUP 7: TWO-STEP INNOVATION AWARD

This proposal is essentially a means of implementing other incentives, with the focus more on competition in defining and qualifying the effort, followed by choice of the appropriate incentive. The incentive selected could relate either to accessibility or allocability.

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10. Illinois Institute of Technology Research Institute. Technology in Retrospect and Critical Events in Science (TRACES). Prepared for the National Science Foundation under contract NSF-C535. n.p., 1968. 118 pp.

SUMMARY

This investigation is based on the historical tracing of key scientific events which led towards five major technological innovations. The data collected were carefully analyzed. This study produced findings which not only substantiated some intuitively accepted beliefs but which also yielded some interesting points that shed new light on the very involved process which leads from research to innovation.

1. In all cases studied, nonmission research provided the origins from which science and technology could advance toward the innovations which lay ahead.

2. Of the key events documented, approximately 70 percent were nonmission research, 20 percent mission-oriented research, and 10 percent development and application.

3. The distribution by performers of key events was as follows:

[In percent]

	University plus college	Research institute plus Government labs	Industry
Nonmission research	76	14	10
Mission-oriented research	31	15	54
Development and application	7	10	83

4. The number of nonmission events peaks significantly between the 20th and 30th year prior to an innovation, while mission-oriented research events and those in the development and application area peak during the decade preceding innovation.

5. For the cases studied the average time from the conception to demonstration of an innovation was nine years.

6. Ten years prior to an innovation, i.e. shortly before conception, approximately 90 percent of the nonmission research has been accomplished; insofar as one can generalize from the results of this study, most nonmission research is completed prior to the conception of the innovation to which it will ultimately contribute.

7. Although nonmission and mission-oriented activities regress during the several years just preceding innovation, it is apparent that the interplay between these types of research activities is important and sometimes even crucial during this terminal period.

8. The presence of interdisciplinary communication is very evident in, and important to, the achievement of innovation.

9. The role of U.S. research has continued to increase relative to foreign contributions. However, foreign research continues to be important to innovation.

10. The study points out the need for a better understanding concerning the two-way interaction between science and technology. The tracings revealed cases in which mission-oriented research or development efforts elicited later nonmission research which often was found to be crucial to the ultimate innovation.

11. Innovations for the next generations depend on today's nonmission research.

PART II. CONCLUSIONS

Socio-Economic Benefits of Innovation

The influence of these five innovations on our society has been made evident: the possibility of the oral contraceptive pill's contribution to the solution of pressing social problems; the role of matrix isolation as a stimulant to the naturally dynamic chemical industry; the inherent design capabilities of magnetic ferrites as applied to several growing industries; the indispensability of the video tape recorder to current television programming; and the electron microscope's gift of permitting us to observe the heretofore unobservable. These benefits to our society are the return, realized through innovation, on prior investment in nonmission research.

The benefits include the growth of a $100 million business in the ethical drug industry; the establishment of significant cost savings for major chemical industries, which cannot yet be evaluated in dollar terms; the creation of a new electrical industry with a projected gross product of over $125 million in 1968; the sophistication of the multi-million dollar television and communication industry; and the creation of an instrument industry whose gross product has now exceeded $200 million.

Nonmission Research and Economic Growth

The early development of our industrial society resulted from innovations dependent upon either the discovery of new sources of raw material, the exploitation of the labor markets, or the infusion of capital in large amounts. In contrast, the five cases considered in this study illustrate that the emphasis has changed over the years and that in general much of our current economic progress is dependent upon the creation of wealth through the exercise of our intellectual and logical powers, rather than through the discovery of new raw materials and labor sources. The role of nonmission research in aiding decisions for development and application is very important. Nonmission research frequently obviates investments into techniques and processes which are later found to have been economically unsound.

The relationship of nonmission research to our economy is, as best, only generally understood. The way in which nonmission research appears to be used to achieve economic gain is analogous to capital wealth. We establish a fund of knowledge against which withdrawals can be made to achieve innovation at a rate satisfactory to society. Of course this "reservoir" of basic understanding is not in any way depleted or consumed by its use.

Dependency of Innovation on Nonmission Research

The innovation of the electron microscope depended almost completely on nonmission research for its achievement. New, and at that time, revolutionary theories in physics, combined with experimental advances in electronics and related fields, were the essential research ingredients. In complete contrast, the video tape recorder (VTR) was preceded by a large number of applied research events and developments which had originated from the 19th Century suggestion that information could be magnetically recorded. Nonmission research did, however, play a very important role in the development of the VTR by providing the theories necessary to understand the way in which development had to proceed. These two innovations represent extremes, in that a more balanced interplay between nonmission research, mission-oriented research, and development and application characterizes most tracings. In all cases, nonmission research provided the origins from which science and technology could advance toward the innovations that lay ahead. The importance of nonmission research to the innovations is made clear by the fact that approximately three-fourths of all the events recorded in the tracings are nonmission work. Equally important is the role that nonmission research plays in initiating lines of thought which evolve into the areas of technical specialization necessary for innovation.

Relationship of Research to Innovation

In order to make decisions about today's research for tomorrow's needs, it is necessary to understand the characteristics of research in its relationship to innovation. The diversity of knowledge, and therefore of research required to achieve innovation, has been an important factor demonstrated in this study. The number of scientific specialties, the number of independent investigators, as well as the combined presence of theoretical studies, experimental investigations, and empirical research illustrated by a study of only five tracings, is suggestive of the great diversity that underlies the entire range of current innovation. Because of the increasing comprehensiveness and sophistication of innovation, it is almost certain that the diversity of knowledge required for tomorrow's innovation will be even greater. Thus, if the increase in sophistication is to be maintained, the breadth and depth of research to be supported must also be increased even though this requires an increase in funding level.

Another important factor inherent in several of the tracings was that of interaction between scientific disciplines and/or highly effective personal communication. The presence of interdisciplinary communication is very evident and its importance to innovation is rather obvious. However, also in the context of communication, a better understanding needs to be achieved concerning the two-way influence between science and technology. The tracings revealed cases in which mission-oriented research or development effort elicited later nonmission research, which often was found to be crucial to the ultimate innovation. A series of illustrations lies in the tracings of the development of magnetic ferrites in which the early development of successful devices stimulated nonmission research to achieve a basic understanding of materials and their properties. Interdisciplinary research institutions, which played an important role in several of the tracings, by their very nature foster both kinds of communication, and the result is illustrated by the significance of their influence on development. Improved communication is a well observed trend within many research activities, and the organizations which support and guide research must increase their emphasis on communication particularly among disciplines and between nonmission and mission-oriented research.

The regenerative nature of research is important to questions concerning the level and allocation of research support. Matrix isolation is a striking example of how the innovation of a technique can lead to the stimulation of research in a multiplicity of areas and at a rate greatly exceeding that which resulted in the initial innovation. This characteristic of nonmission research requires great adaptability within the agency supporting it, commensurate with the adaptability of the scientists themselves in attacking new areas.

Characteristics of Institutions and Individual Scientists

Each of the tracings involved research and development events from universities, research institutes, government laboratories, and industry. These were of foreign origin as well as national. While the degree of their contribution differs with the research category, all types of institutions contributed to each category and specifically to nonmission research. The continued involvement of a variety of institutions would appear to be a worthwhile objective to help meet the need for diversity of research.

The number of individual scientists involved in the five histories, as well as in each individual history, was large. Although there existed prominent individuals who either made multiple contributions or provided important guidance and direction, most of the research events resulted from the efforts of a large number of people. It would therefore appear that the support of many scientists is desirable if one wishes to maintain and increase the rate of innovation.

A significant number of contributions in every tracing were made by scientists outside the United States. The percentage of foreign events has decreased since 1930 primarily as a result of the increased absolute number of research events occurring in this country. However, the importance of foreign scientists to these innovations suggests that the role of international science warrants continued recognition. A variety of mechanisms may have been responsible for the international transfer of knowledge related to innovation. It is not possible to conclude from this study which specific interactions might best be employed to maintain interchange at a profitable level, although the pervading role of personal communication in all interchanges, foreign or not, may be indicative.

Guidance of Nonmission Research to Achieve Innovation

The diversity of research which goes to support an innovation, the variations in timing of nonmission research with respect to innovation, and our inability to forecast the nature of probable innovations preclude the possibility of relating most nonmission research to specific innovations in advance. However, it is possible to discern areas of research which have an increased chance of return over that of others. The activity following the introduction of matrix isolation is an example. The availability of a new technique capable of studying a whole new range of phenomena led to a variety of investigations aimed at fresh insight into familiar but important processes. There is no guarantee that any or all of this research will lead to innovation, but it is clear that significant advances toward that goal have already been achieved.

The ability to introduce new data and points of view based on advances in science is a condition that warrants consideration of increased support and activity. The converse decision is not possible, however. It cannot be said with certainty that a given line of research will never contribute to innovation.

Our very limited understanding of the innovation process, our inability to define innovations well in advance, and the fact that nonmission research precedes innovation by many years seems to indicate that most nonmission research cannot be programmed. However, an analysis of needed innovations to determine their characteristics can help to identify key blocks of knowledge which *might* contribute to innovation. Such analysis coupled with forecasting techniques could aid in recognizing "breakthrough" barriers early. The history of magnetic ferrite is illustrative although admittedly the concept and its influence appears early in time. Clearly progress was limited by lack of detailed understanding of the basic properties of ceramic materials. Studies in crystal chemistry and in the electrical and magnetic properties of a variety of materials provided the knowledge which unlocked the barriers to successful application.

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11. Isenson, Raymond. Project Hindsight; Final Report. Washington, Office of the Director of Defense Research and Engineering. 1969. 218 pp. [Available from the National Technical Information Service, No. AD 495 905].

EXECUTIVE SUMMARY

Project HINDSIGHT was established by the Director of Defense Research and Engineering in his memorandum of 6 July 1965 to the Assistant Secretaries (Research and Development) of the Military Departments.

Objectives and Strategy

The defined objectives of Project HINDSIGHT were:

(*a*) To identify those management factors that are important in assuring that research and technology programs will be productive and that program results will be utilized; and

(*b*) To measure the overall increase in cost-effectiveness in the current generation of weapon systems compared to that of their predecessors (when such can be identified) that is assignable to any part of the DoD's investment in research in science and technology.

The strategy adopted to achieve these objectives involved:

(1) Determining the extent to which new weapon systems are actually dependent upon the results of recent advances in science or technology for their attained increase in system effectiveness, decrease in cost, or increase in cost-effectiveness as compared to a predecessor system.

(2) Determining the proportion of any new technology, required for attaining system characteristics, that was the result of DoD-financed research in science or technology.

(3) Determining significant management and other environmental factors, as seen by the research scientist or engineer, that appear to be commensurate with high utilization of research results.

(4) If the findings of the first strategy indicate a significant reliance on new science or technology, devising a value-cost index (or set of indices) which offers a quantitative measure of the return on investment in research, in terms of the enhanced cost-effectiveness of the weapon systems made possible by the purchased knowledge.

It is emphasized that this study identified only those incremental contributions to existing bodies of scientific and technological knowledge that were utilized in the analyzed military equipments. The strong dependence of these contributions upon the total base of science and technology must be recognized. The reader is cautioned that any conclusions regarding the value of the total knowledge base cannot be validly drawn from the findings presented here.

Hindsight Findings

(1) The identification of specific events in science or technology research, the results of which were utilized in, and were critical to, new weapon systems, was found to be fairly simple.

For most of the systems studied, on the order of 100 to 150 post-1945 contributions from the scientific and technological communities were uncovered. Practical limitations in time and resources, however, permitted only a smaller number to be examined in detail. In no case did the study team feel that it had exhausted the possibilities for identifying additional contributions. Studies of the individual systems were terminated when the study team and the Project Director were quite certain that a representative sample of the contributing Events had been investigated or a 3-month study period had elapsed, whichever came later. Estimates of sample size, made at the completion of the system study, varied from 20 percent for the C–141 cargo aircraft to 75 percent for the LANCE missile system and over 95 percent for the Mark 56 and 57 Naval mines.

(2) The number of Events that were easily identified varied proportionately with the relative increase in effectiveness between the studied system and its predecessor.

For example, the studies quantitatively demonstrate that more new technology was required to progress from the HONEST JOHN rocket to the LANCE missile system than from MINUTEMAN I to MINUTEMAN II.

(3) No category of performing agency was found to be significantly more efficient in the production of utilized research results that other categories.

The distribution of identified RXD Events that came from universities, industry, or the in-house laboratories of the Military Departments agrees, to within a very few percentage points, with the allocation of applied research funds to these categories.

(4) The study's findings demonstrate that the results of research in science were most frequently exploited when the investigator was responsive to recognized needs of the engineering community.

Although the profitable work frequently was classifiable as applied research, in that the scientists was attempting to resolve a very specific problem, it does not appear that specific application per se is a sufficient criterion for predicting usage. Perhaps the most important factors in establishing a high probability of utilization are the degree of awareness (a) on the part of the scientist concerning who in the engineering community needs the knowledge and (b) on the part of the interested engineers as to which specific scientist is working on the problem. Accordingly, research managers must be senstive to the need for communication between the scientific and engineering communities.

(5) A significant number of important scientific contributions came from sources other than contemporarily recognized experts.

Investigation of a sampling of these Events disclosed a fairly common pattern. The performers of the utilized scientific effort and their peers were mutually aware of the exploration each was undertaking, but there was marked disagreement regarding the merit of the approach that eventually found use. In each case the successful performer broke from the peer group, moved away, and found new funding. More than anything else, these examples point out the necessity for ensuring competition within bureaucracy and the necessity for maintaining a multiplicity of funding sources for every scientific discipline and area of technology.

Within this report, undirected basic research in science, refers to tasks not clearly identifiable as part of a larger program that was coordinated by a mission-oriented agency. In general, they are those individual, comparatively small efforts undertaken by one or two investigators in the universities, in some not-for-profit corporations and, to a much smaller extent, in other industry. They are characterized by the fact that they were motivated at the researcher's level by scientific curiosity and scholarly inquiry, and were supported by the DoD upon recognition of the relevance and significance of the researcher's proposal.

Complementing this knowledge accrued through formal education is the engineer's later recourse to codified or tabulated information, such as engineering handbooks and technical references. The second payoff of basic scientific research is identified as the organization of research results into a format readily available for general use. In this way, new concepts of everything from materials characteristics to design techniques have been widely disseminated. Management criteria intended to enhance the usefulness of research results should include recognition of the importance of unifying or codifying information and the requirement that the objectives of supported research be so oriented. Periodic surveys should be made, and research advances in particular subject areas should be consolidated and published in a format designed for use by engineers.

(6) The greatest payoff in terms of ideas leading to enhanced weapons systems has resulted from research in technology—and then, where the research scientist or engineer was intimately aware of problems of the applications engineer.

The transfer of science to technology and technology to application has been found to rely heavily on personal contact between individuals. The communication link is of critical importance, both for advising the scientific community about real problem areas and for disseminating scientific or technological knowledge to the eventual user, the applications engineer.

(7) The popular concept that a market increase in the performance of an existing system generally results from new, key scientific ideas is not confirmed by this study.

The real difference in performance between a weapon system and its predecessor is usually not the consequence of one, two or three scientific advances or technological capabilities but is the synergistic effect of 100, 200 or 300 advances, each of which alone is relatively insignificant. These hundreds of diverse advances must then be fitted and adjusted for a unified operational weapon system. The characteristics of each advance must be carefully "interfaced" with those of other advances. This is substantiated by Project HINDSIGHT data, which generally show that systems applications, rather than new science, inspire science and technology for advanced systems.

(8) A considerable amount of new technology is dependent upon prior specification of detailed requirements.

Analysis of the time relationship of an RXD Event's occurrence to its utilization in the studied system reveals two characteristic patterns. Where the weapon-system development progressed directly from a technological base (exploratory development) to engineering development, there is a marked peaking of Events about the time development is initiated, with about 41 percent for LANCE and 60 percent for MINUTEMAN II occurring after development had started. This situation appears to be incompatible with current procurement policies that stress fixed-price development contracts (with or without incentive fee). Where the weapon system progressed from a technological base through an advanced-development phase and then into engineering development, a much more uniform distribution, devoid of significant peaks, is noted; examples are the Mark 56 and 57 Naval mines.

Project HINDSIGHT did not investigate system-management aspects of the weapon systems studied. It is understood, however, that in at least three cases—the BULLPUP air-to-surface missile, the C–141 cargo aircraft and the LANCE missile system—development was undertaken after assurance was given that the requisite scientific and technological knowledge was in hand. The Event-distribution charts adequately demonstrate that these assurances were not vadid. A major reason for the lack of validity becomes apparent in a study of the detailed Event descriptions. At the time an advanced weapon system is proposed, the design engineer forms his judgments on the basis of experience or the extrapolation of that experience—the more advanced the proposed system, the greater the dependence upon extrapolation. A requirement for research in technology arises when the extrapolation proves to have been overly optimistic.

In view of the potential economic advantages of fixed-price system-development contracts, the matter becomes one of determining how, in the light of Project HINDSIGHT findings, it is possible to ensure that such a contractual situation can be meaningfully established without restricting technological growth. Two possibilities (findings 9 and 10), either or both, are suggested as a solution to the problem.

(9) The increased use of the advanced-development category can be a means of identifying deficiencies and channeling research in technology toward their reduction.

The Mark 56 and 57 Naval mines, developed in an environment that currently could be considered advanced development (R&D category 6.3), demonstrates what can be done. The apparent rate at which technology was introduced shows the orderly progress that is possible throughout development in the absence of a production commitment of an overly ambitious delivery schedule. The investigation disclosed that, during the early development years, the work was accomplished at an essentially constant level of effort. Fixed sums of money were made available for investigations into problem areas that were disclosed as the system's design took shape. Production did not start until a prototype demonstrating that the problems had been reduced was essentially complete. These examples suggest that the greater use of prototype-system development in the advanced-development category, to provide focus and spur to research in science and technology, can be a successful prelude to fixed-price production contracting and still ensure a significant increase in operational performance.

(10) Visibility of research expenditures can be retained by means of budgeting techniques.

Alternatively, fixed-price development contracting might be made feasible by assigning to the Government project manager a degree of control over a portion of the Military Department's technology money (R&D categories 6.1, 6.2 and 6.3) in addition to the engineering-development (6.4) money committed to the contractor. This would allow the project manager to influence the development of the necessary technology for his system, ensure that the technology money was in fact directed into areas of established military importance, and by keeping the funds in the 6.1, 6.2 or 6.3 categories give visibility to expenditures. It is clear that the use of this technology money must remain responsive to the control of the Government project manager to be parceled out as needed. Obviously, great care must be taken to ensure that these funds don't become a "bail-out" resource to cover nontechnical management deficiencies. Examples of the successful application of this approach were found in the development of the Mark 46 torpedo and the AN/SPS-48 radar.

(11) The DoD has required a considerable amount of new technology and has had to fund most of it.

The relative ease with which RXD Events contributing to the capabilities of new weapon systems were identified, the number and diversity of those Events, and the recognition that the same level of the utilized science or technology almost never existed at the time of engineering development of an operationally similar predecessor system combine to demonstrate irrevocably that a considerable amount of truly new technology was required for an advanced weapon system.

It is estimated the Military Departments spent about $10 billion during 1945–1963 when most of the identified Events occurred. For the same years, another estimate places expenditures for research in science and technology by industry and other non-Defense sectors of the economy at approximately $7 billion. The finding that the acquisition of 85 percent of the utilized new scientific and technological information was financed by the Military Departments becomes significant in view of the relative size of the two amounts expended.

We may conclude from these two observations that a great deal of new knowledge was required for an advanced weapon system and the Department of Defense could not rely on other sectors of the economy to generate it. This conclu-

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sion is strengthened by the finding that, of the remaining 17 percent not directly funded by the DoD, 9 percent was paid for by defense-oriented industries and was thus indirectly funded by income from previous Defense contracts.

(*12*) *Transfer of technological information is at a reasonably high level within the defense-oriented community.*

Approximately 300 separate organizations or corporations have been identified as having contributed to the fund of new knowledge. About 20 of them had significant responsibility as prime contractors in the development of one or two of the studied systems. Despite the great number of participants, over 80 percent of the RXD Events (but an estimated 20 percent within the set of systems studied) are known to have found application in more than one weapon system. At the very least, therefore, it can be claimed there are strong indications that information transfer within the defense engineering community is at a usefully high level.

The Project HINDSIGHT study did not attempt explicitly to identify alternative technologies used in the several systems where one of the alternatives theoretically might have satisfied all users. The number of cases involving such a situation was so small as to appear statistically insignificant.

(*13*) *The performance of the in-house DOD laboratories appears to be consistent with the numerical strength of their professional personnel.*

After the sources of the utilized new science and technology were identified, it was possible to examine time-dependent trends in terms of the relative productivity of the various sources. As far as new science is concerned, the available data are not statistically significant. A marked trend, however, is observable with respect to technological activity. Early in the 1945–1958 period, about 51 percent of the new technology was coming from the in-house laboratories of the Military Departments, with 42 percent from industry and 7 percent from the universities. By 1959 the balance was reversed, so that 36 percent was coming from the Defense laboratories, 58 percent from industry, and 6 percent from the universities (primarily university-operated centers such as the Research Laboratory for Electronics or the Instrumentation Laboratory at MIT).

During this whole time, the scientific and engineering strength of the non-DOD community essentially quadrupled, while the strength of the in-house Defense laboratories less than doubled. Thus, the change in relative output appears to reflect only the relative increase in strength.

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12. Jewkes, John, David Sawers, and Richard Stillerman. The Sources of Invention. 2d ed. London, Macmillan, 1969. 372 pp.

Chapter IX. Conclusions and Speculations

> It is a fitting inquiry what are really the intellectual characteristics of this age: whether our mental light has not lost in intensity at least a part of what it has gained in diffusion; whether our 'march of intellect' be not rather a march towards doing intellect, and supplying our deficiency of giants by the united efforts of a constantly increasing multitude of dwarfs. . . . Where, then, is the remedy? . . . It is in the distinct recognition that the end of education is not to teach, but to fit the mind for learning from its own consciousness and observation. . . . Let the feelings of society cease to stigmatize independent thinking.—John Stuart Mill.[1]

I. The Continuity of Things

There is nothing in the history of technology in the past century and a half to suggest that infallible methods of invention have been discovered or are, in fact, discoverable. It may be true that in these days the search for new ideas and techniques is pursued with more system, greater energy and, although this is more doubtful, greater economy than formerly. Yet chance still remains an important factor in invention and the intuition, will and obstinacy of individuals spurred on by the desire for knowledge, renown or personal gain the great driving forces in technical progress. As with most other human activities, the monotony and sheer physical labour in research can be relieved by the use of expensive equipment and tasks can thereby be attempted which would otherwise be wholly

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[1] 'On Genius', *Monthly Repository*, n.s., vol. vi, 1832, pp. 649–59.

impossible. But it does not appear that new mysteries will only be solved and new applications of natural forces made possible by ever increasing expenditure. In many fields of knowledge, discovery is still a matter of scouting about on the surface of things where imagination and acute observation, supported only by simple technical aids, are likely to bring rich rewards.

The theory that technical innovation arises directly out of, and only out of, advance in pure science does not provide a full and faithful story of modern invention. As in the past three centuries, there is still a to-and-fro stimulus between the two; each has a momentum and a potential of its own. The case for scientific enquiry is not a utilitarian one. It may be that the flow of inventions is just likely to be increased by stimulating the fuller exploitation of the myriads of technical possibilities inherent in the existing stock of scientific knowledge as by increasing that stock.

Experience suggests that most *specific* inventions were not foreseen: they had an element of the accidental in them, they represented the last, and therefore the crucial, step between the uncertain and the certain. And the more revolutionary they were the less foreseeable they were. No one, least of all the inventors concerned, predicted the discovery of penicillin, nylon, polyethylene, the transistor, insulin, radio, the cyclotron, the zip fastener, the first aniline dye, the vulcanisation of rubber or many other cases which could be quoted. More generally, in so far as specific inventions are empirical, they cannot be predicted.

But if the details of the future are hidden, are there reasons for believing that it is still possible to perceive in a broader way what is to come? Is there a valid parallel, for example, between plotting the broad surge of technology and drawing up (say) a table of the movements of the tides? An affirmative answer can be given here only if invention is accepted as a 'social process', as a movement which has a direction and a force independent of the influences of individuals.[1] The reasons put forward for supposing that inventions will emerge, in their due and proper season, as the inevitable incidents in a forward sweep of history which is humanly comprehensible and can be tabulated may now be examined.

The correct attitude would seem to be to accept the changes brought about by invention and to deal with these changes, as and when they occur, by methods adjusted on each occasion to the character of a specific and perceived problem. It is well to remember that, in the past, the prophets have tended to press upon us hasty and hysterical action because their views about the future have been founded upon a narrow and unsubtle picture of possibilities and an inadequate grasp of the power of communities to resolve their problems step by step. It is easy to list the major alarms that they have raised: progressively extensive unemployment as machines came to be more widely used;[2] absolute shortages of raw materials because the use of natural resources was not being controlled; the social dangers of increased leisure as communities became richer; the spiritual and moral hazards of societies where more and more tasks were mechanized and less work left to the healthy use of hands and eyes; the prospects of science and technology being devoted wholly to the designs of individuals plotting to concentrate power in their own hands.

Is it in fact true that nowadays inventive ideas are more quickly seized upon and exploited and their potentialities more swiftly diffused throughout the community in the form of higher standards of living than heretofore? We do not know because these things cannot be measured in their totality. Is it true, for example, that standards of living are rising more rapidly than ever? Because this cannot be measured, it is seductive to reach snap generalisations based on a few spectacular illustrations. On the other side, however, it may be asked whether there is much cause for self-congratulation in the fact that although a jet-propulsion plane flew in 1939, it was not until the end of 1958 that the jet-propelled airliner became established as a regular part of air transport? Or that colour television was

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[1] It is interesting to watch H. G. Wells, in his efforts to establish the proposition that we can generalise about the future of humanity, trying to escape from the embarrassing fact that there are great men, whose appearance cannot be predicted, but who presumably have some influence on events. He concludes, 'the great man cannot set back the whole scheme of things; what he does in right and reason will remain, and what he does against the greater creative forces will perish'. ('The Discovery of the Future', *Proceedings of the Royal Institution*, vol. 17, 1902.) In this form the cult of prediction is really a kind of religion.

[2] A prediction which was most confidently and most widely made in the 1930's was that the introduction of the cotton picker would create unemployment and the most serious social problems in the southern states of America. The cotton picker is now very extensively employed but none of the predicted consequences have arisen. The latest illustration of this is the scare about 'automation' which it is said threatens us with unemployment on an unprecedented scale. (N. Wiener, *The Human Use of Human Beings*, p. 162.)

introduced so slowly? Or that the work over 30 years of the scientists in connection with silicones only began to find commercial applications after 1945? Or that the diesel-electric locomotive was brought to the point of general use only in 1935 although the diesel engine was invented at the beginning of the century and systems of electric transmission had long been known? Or that no automatic transmission system was adopted on any scale for the light motor car until 1959? Or that it took a quarter of a century for industrialists to recognise the value of taconite? Or that the improvement in the electric battery has been so incredibly slow.

In the twentieth century, apart from the special awards to war-time inventors, the emphasis of public endeavour has been upon institutions and not upon incentives. Governments have sought to encourage invention by setting up research organisations under their own control, or have subsidised research groups set up otherwise. Firms themselves have established industrial research laboratories and, at least in the United States, private enterprise has created specialised research organisations working for profit. The underlying principle, rarely formulated precisely but ever present, has been that originality can be organised; that, provided more people can be equipped with technical knowledge and brought together in larger groups, more new ideas must emerge; that mass production will produce originality just as it can produce sausages.

Under the influence of this doctrine the process of discovery and invention is becoming progressively institutionalised. The disposition of individuals to pursue their own ways with their own resources is weakened in many ways. High taxation (which in part is high because governments collect resources from the citizen for the purpose of stimulating public scientific and technical research) makes difficult the accumulation of private means. The lure of adequate equipment, congenial intellectual society and a secure livelihood provided by the institution is strong. In turn, institutions will naturally place emphasis upon the formal training and academic qualifications of those they employ: they will therefore become increasingly staffed by men who have been subject to common moulding influences. There is a possibility of in-breeding from which the more eccentric strains of native originality may be excluded.

It is, therefore, not wholly perverse to pose the following question. *If* present trends continue for any length of time, it is not improbable that all technical research will be carried on by men with high university degrees in institutions where a measure of organisation is necessarily imposed on their work; that such institutions will be looked upon as the sole source of technical ideas; that emphasis will be laid on the need for, indeed, the duty of, research workers to submit themselves to team work; that the activities of the groups will be planned with a view to eliminating overlapping efforts and "filling obvious gaps". Is this the kind of system most conducive to innovation?

V. The Virtues of Eclecticism

Knowledge about innovation is so slender that it becomes almost an impertinence to speculate concerning the conditions and institutions which may foster or destroy it. But the evidence in this volume points to the conclusion that, in seeking to provide a social framework conducive to innovation, there are great virtues in eclecticism. The conditions under which inventions have arisen up to the present day are so diverse that safety would seem to lie in numbers and in variety of attack. If past experience is anything to judge by, crucial discoveries which add to the conveniences of life may spring up at practically any point and at any time. The only danger would seem to be in plumping for one method to the exclusion of others. In so far as society can usefully interfere—and there is much truth in the belief that "the only thing men of power can do for men of genius is to leave them alone"—its task would be to try to maintain a balance between the different sources of inventions, to strive to prevent any one dominating to the exclusion of others.

The prospects in the Western countries for keeping open numerous channels are not altogether unpromising. There are some natural defences against the dangers of a vast, tidy, monolithic national organisation of technology and science. Autonomy of science and technology in the universities, while threatened by recent events, is still strongly believed in; it is much to be hoped that scientists and university administrators will recognise and resist the encroachments of outside bodies and the lure of tempting grants which turn the universities into tied houses. If science has a 'social' function it is to defend its self-government. It is all to the good that there are very many different types of research institutions, ranging from the university laboratory to the private enterprise research organisation, providing a wide range of experiment and competition in the different ways of handling research workers and, conversely, offering to each worker some choice in the conditions under which he operates. It is perhaps not altogether accidental that the two countries which are often claimed as possessing the greatest inventive energy, the United States and Germany, have the greatest diversity of types of research organisations. And in Great Britain it would be a mistake to suppose that the existence of an extensive chain of industrial research associations, which show very varying levels of achievement, render unnecessary or undesirable other technical research organised in different ways and working with different motives. Again, the very number and diversity of approach of the research laboratories of industrial corporations might create a bar to excessive uniformity of method and outlook. So long as firms are in competition it may be supposed that their rivalry will extend to the best manner of handling their research policy and that the better system will prevail. Thus there are not a few firms which are very conscious of the danger that prolonged university training may inhibit or destroy the inventive faculty, and which therefore recruit their research workers from local technical schools or even from among the promising youngsters at the benches. There are some firms which try, difficult though it may be, to provide for at least a few men of promise the kind of freedom which an individual inventor or the university worker would possess. There are some who feel that the best use they can make of whatever resources they can afford for research is to support university activities.

To put the matter concretely: the next time that someone invents, as Whittle invented, a new type of engine, is there any way in which the individual inventor can be spared the neglect, discouragement, or active obstruction which was Whittle's experience? The answer may be no. It may be that, clumsy and wasteful as the process seems, no more effective way can be found of separating wheat from chaff among individual inventors than to submit them to this kind of rough jostling. For, it may well be argued, if there were no method for enforcing standards and side-tracking the charlatans, we would be overrun by a jungle of cranky ideas. In science the task of sifting the spurious from the real is conducted by the profession itself; in commerce the test is that of the market; in art in most countries it is settled by a combination of market forces and public arbitrament. With invention, except in war-time, the final test is, and of course must always be, again the market; but under the patent system the State makes a preliminary and rudimentary distinction between those ideas which have inventive merit and those which do not, and then confers upon the originators temporary protection in the market. The question at issue is whether this is the right combination of obstacles and spurs for blocking abortive novelties but not suppressing seminal minds, whether we pay just about the right price in good ideas lost to society in order not to be pestered unduly by the charlatans. Could we in any new ways provide a sanctuary for the inventor which would not become a rest home for freaks and oddities?

One conclusion can be put forward immediately with confidence. So long as the survival of the individual inventor is not utterly despaired of (and the evidence of the preceding chapters suggests that there is no need to do this) and so long as nothing better can be suggested for the purpose, there is a very strong case for the retention of the patent system.

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13. Kelly, Patrick, and Melvin Kranzmerg, eds. Technological Innovation: A Critical Review of Current Knowledge. San Francisco, San Francisco Press, Inc., 1978. 08 pp.

The Argument

(By Charles Susskind and Martha Zybkow)

Part I

1. ECOLOGY OF INNOVATION

Technological innovation is an ecological process that spans a range of activities from the initial idea through development, production, and diffusion; it is a complex response to either need or opportunity, requiring creativity and resulting in the introduction of novelty. Exogenous elements such as human wants, social values, and the economic structure affect the nature and rate of innovation itself; for, like any creative endeavor, it arises from the interaction between individuals and the socio-cultural environment. Because innovation brings about changes in how people work and live, and ultimately how they think and act, prediction of the higher-order effects of new technology before its application is important.

Aspects of the innovative process are of interest to a spectrum of disciplines. Researchers in economics, sociology, and anthropology, for example, continuing to develop models of the process in an effort to understand it better. Although focused studies with limited emphases increase our insights, they cannot provide a complete understanding of the entire process. It is tempting to simplify innovation into a linear process beginning with invention and culminating in dissemination. But such a model cannot explain the interaction of components and ignores the reciprocal relationships between structure and function. A holistic, "ecological" approach that transcends the bounds of disciplines is better suited to the concepts involved.

The conceptualization of innovation as part of a large, dynamic system is vital to its comprehension, but we must focus on the most relevant forces relating to technology; structuring devices must be imposed to create a manageable framework on which to base investigation. In this study, the authors order the components of innovation by the context in which the process takes place into "indigenous" factors (from problem definition to production and diffusion) and those that comprise the larger "exogenous" system (e.g., values, institutions). Once this classification is made we can relate the parts, see the relationship of function and structure, and better understand the nature and effect of their integration. Finally, the subject is divided into two phases, innovation and diffusion, as an aid to organization. This classification differs from the classical division of innovation into individualistic (heroic) and determinstic, as well as from the opportunity-need-genius triad of R. B. Dixon or the linear approach of A. P. Usher.

2. THE WORLD OUTSIDE

The three classical elements of the exogenous system affecting innovation are values (individual or group preferences), endowments (inputs to innovation: knowledge, capital, labor, energy, and materials), and institutions (human organizations that develop to serve goals defined by societal preference).

Values.—Linking the role of values to innovation is important because capitalism played a crucial part in the development of technical innovation as a central activity of modern Western society. The degree of societal support for research and education reflects the values supporting scientific and technical knowledge. Current studies show that there is growing public awareness of the broader implications of innovation. Concern over the harmful side effects of new technology has given rise to public-interest groups. Changing values are also being "institutionalized," for example in environmental legislation, pollution regulation, and (in the USA) the creation of the Environmental Protection Agency and the Office of Technology Assessment. This desire to evaluate and control the effects of technology may change the rate and kind of innovation in the future.

Endowments.—Interaction of science and technology, which has increased the pace of innovation in the past, is the result of the high value placed on the fruits of innovation. However, most innovation does not arise directly from the application of scientific knowledge. A model of a "pulling and pushing" relationship between science and technology has evolved from current studies relating new discoveries and innovation.

New technological innovation is stimulated by "readiness" as well as knowledge. Existing technology is an important tool for advancement. Because technologies are interdependent, advances in one field create the need for innovation in another. The quick mechanization of British textiles during the Industrial Revolution shows how innovation is spurred as new opportunities are created. Improving the spinning process called for faster weaving and in turn a better, faster way of preparing raw cotton.

Innovation also requires money for new ventures, shifts in the quality of labor, and the supply of specific natural resources. In the market structure, demand stimulates and to some extent directs the incentive for innovation. Natural resources and the supply of scientific knowledge are also important. Growth in knowledge decreases the cost of specific inventions. The substitution of materials and energy sources also aids in increasing productivity and lowering cost. Although the range of isolated substitutions is broad, students of systems dynamics stress that in the world context, most resources are finite and in the long run the substitution model cannot hold up. Limits to growth rest in the limits of "substitutability." This bound is set by human values as well as by natural supplies.

Institutions.—In the West, the market mechanism provides incentive and legitimization for decisions. Society highly values the products of current technology; the economic structure ought to support the most efficient use of existing resources. Schumpeter and Galbraith argue that competitive organization is not necessarily the best impetus for innovative activity; as technology changes, another type of organization may prove more suitable. This view leads to an examination of the relationships among firm size, market structure, and innovation. Studies have revealed a positive relationship between firm size and the amount of R & D expenditures (and patent activity). According to Schumpeter and to Galbraith, industries in which large firms predominate are more innovative. Smaller firms engaged in close competition want (and need) to innovate more but have less financial and organizational capacity. Ease of entry into an industry is another component of market structure under study. Expense, lack of patents, and difficulty in competing with established firms impede entry to certain industries. In such industries the pressure to innovate is smaller; yet easy entry may actually discourage experimentation and investigation of new areas. More study of the interaction of market structure and innovation activity is needed.

Although the government theoretically plays a minor role in a free-enterprise economy, the U.S. government has become increasingly involved in fostering new technology. It contributes over one-half the nation's R & D funds and is as important factor in determining in which areas of technology innovation will take place. Regulation and control modify the economic institutions that bear on innovation, directly through the patent system and tax structure and indirectly through regulative bodies. A "map" of political institutions and public policies that would indicate the effects of each on innovation and the overlaps and conflicts among them would aid further study.

3. THE PROCESS OF INNOVATION: THE ORGANIZATION AND INDIVIDUAL CONTEXTS

The institutional form of innovation has come to predominate, in part as the result of the belief that creativity can be a deliberate and controlled function of the organization. This assumption makes understanding of the creative process imperative. The firm must be able to read external opportunities and circumstances and utilize this knowledge internally. This linkage of environments is assumed to take place at the policymaking level of the firm.

The Individual Inventor-Entrepreneur.—Despite the growth of institutionalized innovation, there are proponents of the individual inventor who argue that the increase in the research force has not been matched by the rate of innovation. However, the Charpie Report (1967), which supported this view by a statistical approach spanning this century, missed the change under way at the time of the study; the individual was giving way to the group worker in organized research laboratories.

The role of the independent inventor has been studied from sociological and psychological viewpoints; but for the purpose of the present study, the context in which innovation takes place is all-important. The function of the inventor must be linked with the entrepreneurial function, which musters the financial support and the managerial and promotional skill necessary for innovation. The phenomenon of "spin-off" firms specializing in invention and development to the point of application is a product of complex technology, which requires knowledge and management beyond the capabilities of a single individual. These firms perform the role of inventor-entrepreneur.

Organized R & D Within the Laboratory.—Organized structure is a major determinant of the function of R & D within the firm. Structure, strategy, and policy interact to influence the orientation of the laboratory, the characteristics of the projects generated and funded, and the effectiveness of R & D. In the past most R & D was subjected to the same hierarchical control and coordination as the firm's other organization functions. Two models (ideas and information flow, and process-phase) were proposed when study of the R & D process began. A different model emerged in the 1960s as a response to change in organizational development, a model that focused on the two stages (innovation and diffusion). In an effort to improve the original two models, project-dominant and phase-dominant composite models have been developed. Various types of projects fit one or the other model better.

Several orientations can be associated with a firm or laboratory. One set is the basis for the process-phase model (i.e., research, development, engineering, etc.); another is the notion of offensive vs defensive R & D (related to the "leader vs follower" notion of firms). The view held by management regarding the proper balance of the R & D program can directly affect the ideas generated, submitted, and undertaken within the laboratory. Dilemmas arise when the relationship of the organizational structure with the nature of the projects undertaken is examined. Organizational conditions most suitable for initiation are opposite to those suited for implementation. The best organization depends on the environment: "mechanistic" (hierarchical and authoritarian) organizations are more effective under stable and relatively certain conditions, whereas the converse is true for "organic" (adaptive and informal) organizations.

Organized innovative efforts change and control individual judgments and activities. However, pre-project activities of problem definition and idea generation cannot be as directly controlled as later project activities. Social-psychological influences of intra- and intergroup relations are important in this early stage. The researcher's perception of his own freedom, supervisory authority that keeps in touch and allows freedom of action while making the needs of the firm understood, and work groups that share information and ideas and are receptive to outside consultation are elements that enhance creative activity. Although relevant variables are now well identified, relatively little has been written about their interdependence or the indirect influence that management can exert, just as the recognition of needs and demands in its environment and the input of technological information are crucial to a firm's success, internal appreciation of the firm's needs and information flow within the organization are important. Social networks of influence and information flow that are primarily informal and oral are an important area in which indirect influence can be exerted. Since ideas are submitted only if the originator feels that the needs and means for development will be seen as relevant by management, more should be done to foster understanding of the mutual influences and interactions between management and researchers and among various levels of the organization, as well as among the researchers themselves. The importance of project selection is stated as follows:

"Of all the subtopics in the literature of organized innovation, R & D project selection may have received the most attention, as it is a focus of both 'idea flow' and 'process phase' models. The R & D project selection decision is a process by which an intermittent stream of changes are made in lists of currently active and proposed projects. The project-selection process includes generating alternatives, determining the appropriate time to make a change, collecting data, specifying constraints and criteria, and recycling. The decision is complicated by multiple decision criteria which has no natural, common, underlying measure and whose relative importance varies over time. The decision may require contributions from several different organizational levels which are participating in a hierarchical, diffuse planning and budgeting process. Our present descriptive knowledge has not yet been integrated into a framework which offers promise of improving the process."

How the social-psychological environment affects the performance of scientists and engineers is another important topic. Effective workers were found to be self directed, able to interact with colleagues, doing diversified work, and exhibiting individual work styles. An investigation of the causality of effectiveness revealed that performance precedes favorable organizational conditions; productive researchers were rewarded with better conditions. "Thus performance should be viewed as a cause as well as a result of change." Prevalent in high-performance groups was an open exchange of information and ideas, and good interaction with supervisors.

A final area of consideration is the transfer of R & D to implementation and utilization. This process occurs when technological output becomes an ongoing capacity (production, marketing, sales). Approximately 75 percent of total innovation costs are spent on implementation. The transfer of R & D results requires a coupling of structure, function, information, and authority. Various organizational forms are used to facilitate this transfer. This is a problem area of great importance but the one for which there is the least information.

4. THE DIFFUSION OF INNOVATION

Research to date on the diffusion process is primarily oriented by sectors that are social systems (such as consumers, agriculture, government, industry). The three basic traditions of approach are the social-psychological, the economic, and the "geographical." Diffusion evidently occurs in an outward-spreading movement, with new adoption taking place mainly near existing adoptions. Personal communications and direct observation are the basic channels for diffusion. This conceptualization emphasizes effective flow of information. The interaction of propagators and adopters implies the existence of a social system.

The economist Mansfield identifies key factors in an innovation's rate of adoption as profitability, uncertainties (complexity, observability, and degree of consistency with existing ideas), extent of commitment, and rate of reduction of initial uncertainty. The findings of his 1970 study of intrafirm research and innovation, in which he investigated the relationship between technological change and economic growth, are of interest in the social-psychological realm. The diffusion process is slowed by lack of knowledge and by resistance to change. Nonuse of new innovation is primarily the result of unprofitability. Better educated owners tend to be early users. Resistance to change entails social, cultural, and psychological components. The effect of this resistance on the propagator's strategy is seen as an important topic for future research.

The "classical diffusion model" remains the major approach to a unified conceptual structure for diffusion. This model concentrates on innovation, communications channels through which it is diffused, the concept of a social system, and time (since the adoption decision is a process rather than an act). However, this approach does not provide an adequate framework. A workable theory should include the characteristics of adopters, of innovations, of propagation mechanisms, and of the aforementioned sectors, which are networks of communication. In previous studies, the functions of social interaction have been stressed over structural characteristics. Research plagued by the other-things-being-equal syndrome has produced a static listing of influences: opinion leaders are identified, early adoption is shown to depend in part on early possession of information, communications and information networks are mapped, and so on. However, in the absence of cross-sectoral studies, sector influences on internal diffusion of innovation and the relative importance of these influences remain poorly understood.

The adopter cannot be severed from the organizational structure or from the informal social system in which he operates. The structure of an organization influences its adoption behavior and reflects the judgments of its leaders. Individuals within the organization look to peers and superiors for confirmation of their opinions. Adoption can be impeded by resistance to change and undereducated decision makers.

Diffusion can be either adopter-dependent or adopter-independent. The social-psychological and economic-industrial traditions have similar lists of adopter-dependent characteristics. For example, the concept of "relative advantage" extends beyond possible profitability to prestige and uncertainty, and depends on the adopter's perspective. Trialability (the extent to which initial adoption is reversible), the adoption of information (i.e., a better way of doing something), and the proprietary or nonproprietary nature of information are adopter-indepenent traits. Determination of the effect of these characteristics on adopter behavior merits high research priority.

Propagation mechanisms are agents, agencies, and vehicles of communication whose primary function is propagation. They provide or increase observability. Technological information "gatekeepers" within an organization, the mobility of engineers within an industry, professional societies, and a broad range of government agencies and programs serve as propagation mechanisms. Quite likely the diffusion of innovation is primarily an oral process. In mass media, information programs and advertising serve as propagators.

The development of a general theory encompassing the above elements requires new questions to be directed at the integration of various aspects of the diffusion process.

5. OVERVIEW AND PROSPECTS

The first part of this report has attempted to determine what is known and what should be known about the innovation process. The specific objectives were to synthesize a diverse literature, to identify gaps and weaknesses in our understanding, and (indirectly) to advance that understanding. Because the subject embraces a wide range of variables of interest to scholars of many disciplines, emphasis on the interdependence and complementary role of the several fields that have contributed to the research on innovation was an additional objective. The investigation was made at several levels of aggregation. It has identified process phases and facets, integrating and at times extending existing conceptualizations. Implicit in the works examined and underlying the institutionalization of the innovation process is the belief that the process can be deliberately altered (i.e., made more systematic) to aid in the creation and diffusion of innovations. However, increased understanding and control depend on the development of a comprehensive theoretical framework. The authors stress the need for conceptual work to achieve this framework.

PART II

6. INVENTORS: THE PROBLEMS THEY CHOOSE, THE IDEAS THEY HAVE, AND THE INVENTIONS THEY MAKE (T. P. HUGHES)

The author distinguishes three early stages of innovation—problem identification, idea-response (formulating ideas that will lead to a solution), and invention (ideas given form)—as exemplified by accounts of three inventors at work and other information drawn from Usher's *History of Mechanical Invention* (1954), Gilfillan's *Sociology of Invention* (1935, 1971), and his own *Elmer Sperry* (1971). This approach reveals the individual's ability to synthesize thoughts and activities in his environment. The work of Edison (1847–1931), Sperry (1860–1930), and Midgley (1889–1944) spans a period in which there was strong support for independent inventors. Although each man represents a different type of inventor—heroic inventor, transitional figure, and industrial research scientist—many similarities appear in the three case histories.

Similarities in these case histories help reveal important components of the innovation process. Since inventors mostly solve existing problems, it is important to see how problems emerge. Change generates incomplete patterns, reverse salients, and imbalances. The author states, "Each interpretation and each case reinforces the conclusion that complex change within even more complex change is the process under way when innovation is occurring." An inventor identifies a weakness in a system and seeks to correct the problem. Among factors affecting an inventor's project selection are his education, experience and talent, anticipation of funding and a market, and availability of R & D facilities. Seeing what other researchers have done allows the inventor to see the focus of prior work and find points that need attention. The generation of a solution is a creative act, difficult to analyze. Idea response is a process of small steps. The cases examined show that analogies are employed, similarities in superficially different problems are seen, and earlier solutions aid in finding new ones.

7. TECHNOLOGICAL INNOVATION AND NATURAL RESOURCES: THE NIGGARDLINESS OF NATURE RECONSIDERED (NATHAN ROSENBERG)

The purpose here is to examine the relationships between patterns of resource scarcity and the innovative process. The supply of natural resources has long been a concern to economists. Malthus envisioned a bleak future as exponential population growth taxed the capacities of a fixed supply of land for food production. Fixed resources, population growth, and diminishing returns became the foundation of classical economics. Although focus shifted from arable land to other resources needed for an industrializing economy in the late 19th Century, economists continued to be preoccupied with finite supplies. The conservationist view is a modern form of an old theme. With growing concern over underdeveloped countries, the problem of population growth again receives attention.

8. THE ECONOMICS OF INDUSTRIAL INNOVATION: MAJOR QUESTIONS, STATE OF THE ART, AND NEEDED RESEARCH (EDWIN MANSFIELD)

Problem areas of industrial innovation interest economists. They concern the nature of the innovation process, the appropriateness of the existing rate of innovation, the determinants of this rate and its relationship to industrial organization, and technological forecasting. Mansfield evaluates existing economic research in these areas, focusing on the individual firm, and suggests what kind of research is now needed.

Various models describe the phases involved in the innovation process; the relative cost (and time) of each phase vary among inventions. Market and/or production need seem to be a more frequent inducement for innovation than technological opportunities. Although in many industries formal R & D is responsible for a minority of innovations, a larger percentage of major important innovations seems to emanate from it. Profitability is important in shaping public and private policy. In the early and middle 1960s the rate of return from investment in technological innovation appeared to be high. Current estimates of the profitability of such investment is one of the three key areas in need of further study. An analysis of the sources of innovation and the characteristics of innovators is also needed. Finally, success of initiated R & D projects in various firms requires investigation.

What is the proper rate of innovation has received little attention. Various levels within a firm's organization (top management, production, marketing, R & D) have different vested interests in change. Top management (which has the greatest control) often feels that the rate is too slow. A main barrier to faster implementation results from poor exploitation of R & D output by the marketing and production departments. The rate of innovation is also important to society as a whole. Does the market economy facilitate enough R & D? Should more attention be paid to the difference between the private and social costs and benefits of new technology?

The optimal rate of innovation is a political as well as economic question. Although the problem is complex, four types of studies would be of great use: (1) We should attempt to estimate better the social return of various innovative activities. (2) We must examine how firms trade off various kinds of risk (e.g., probability of technical or commercial completion and economic success). (3) Studies concerning the optimal extent and kind of international specialization are needed because capabilities and R & D resources in most countries are limited. (4) We must develop better measures of the rate of innovation.

As to the determinants of the rate of innovation and its relationship to organization, they depend on factors that influence profitability of technological change (demand, inputs, proportions, availability, etc.). Among the important factors operating at the firm or industry level: the way R & D is coupled with marketing and production, the types of analytical techniques used to manage innovation, the size and sophistication of the relevant market, and the availability of risk capital. More information is needed by policy makers about these factors. The effect of organization, strategy, and personnel changes on innovative performance, and information regarding venture capital deserve focused study. Firm size and market structure also affect the rate of innovation. Although the traditional idea that efficiency is maximized by competition is disputed by Schumpeter and Galbraith, studies have shown that small firms are important for the initial phases of R & D. Evidence indicates that bigger firms get less innovative output per dollar of R & D than smaller ones. Some industry concentration promotes more rapid innovation but high concentration (a small number of independent sources) does not. Moreover, entry of new firms and a mixture of firm sizes both increase innovation; in highly fragmented industries technological change is hampered. Information about economies of scale, the cost of innovation in various industries, and recent major innovations (and their innovators) in a broad range of industries is needed.

As to technological forecasting, studies measuring the track record of various techniques would aid in assessing which method is best under particular circumstances. It seems likely that a clearer understanding of the process of technological change must precede improved forecasting techniques.

9. TECHNOLOGICAL INNOVATION IN FIRMS AND INDUSTRIES: AN ASSESSMENT OF THE STATE OF THE ART (R. S. ROSENBLOOM)

The concept of strategy may offer a framework that would help explain how organizations and environmental elements influence the rate and character of technological change. These factors "can meet the test of maleability, since the elements of the organizational context are within the control of corporate management, whereas the external factors are influenced both by corporate behavior and public policy." The chapter focuses on issues that pertain to policy makers and adminstrators.

Studies of particular innovations have led to a basic definition of the innovation process and have identified its elements and their interrelated nature. Although central tendencies have been found and crucial factors identified, no adequate theory has evolved to explain their relative importance of why variations occur in innovation among firms and industries.

Investigation at the firm and industry level is helpful in constructing theoretical frameworks. Two tendencies prevail. Economists, examining the implications of firm size and industry market structure, focus on the external environment and address problems of public policy. Behavioral scientists focus on the "inner environment" of the firm that concerns managers. They are interested in the relationship between technology and the structure of organizational systems. A firm's tasks determine the organization best suited to it. The technologies the firm uses may also aid in defining the most effective organizational form; moreover, certain structures may be more or less conducive to technological change. Studies exploring the relationship of organization to environment stress the importance of environmental diversity and uncertainty, structural formality and managerial orientation. Greater differentiation of units with an organization and a high degree of integration across units are characteristic of firms with good performance.

A synthesis between the approaches of economists and behavioral scientists is needed. The firm constantly interacts with its environment. External forces such as competitor behavior, consumer demand, and public policy help shape the environment; whereas organization structure and the kind of technology used affect internal operation. Top managers can influence both internal and external factors. For example, they can bring the firm into new markets, pursue a financial policy that exposes the firm to uncertainty, stimulate sales through marketing policy, and influence consumers.

Technological change can be viewed as a dependent variable that results from the interaction of structural context and the innovative process. The implementation of strategy means turning abstractions into more concrete forms, which gives shape to organizatinal structure. Technology is thus not entirely outside the control of managers.

10. REVIEW AND ASSESSMENT OF THE METHODOLOGY USED TO STUDY THE BEHAVIORAL ASPECTS OF THE INNOVATION PROCESS (C. F. DOUDS AND A. H. RUBENSTEIN)

Studies of the innovation process should lead to the development of theories that will assist managers and policy makers in their decisions and actions. However, a lack of well-developed and consistently applied methodology for such studies hinders the development of adequate theories. In this chapter, several types of methodologies are described and representative examples are appraised to further the development of research strategies. Much of the literature on innovation reflects three basic methodologies (discursive, case studies, field studies); and a fourth type is of particular importance (field experiments).

11. ASSESSING THE KNOWLEDGE OF INNOVATIONS IN NEGLECTED SECTORS: THE CASE OF RESIDENTIAL CONSTRUCTION (W. P. STRASSMANN)

Assessing technological change in neglected sectors such as public services and health care is difficult. Not only is their output qualitative rather than quantitative, but these fields are poorly understood in all respects. Residential construction is a "halfway house," providing both physical objects and a flow of services. Barriers among materials producers, designers, builders, and owners are responsible for the inadequate amount and direction of innovation in this sector.

During the Industrial Revolution theories and tests improved types of construction after they were already in use. Utilization of new materials such as iron and reinforced concrete also began with practice and was followed by theory. As the production processes changed, housing technology was also transformed. For example, efficient mechanical saws reduced the cost of thin boards and resulted in the invention of balloon framing. Among factors that restricted experimentation were the separation of building from the fabrication of building materials, the insulation of contributing occupations (leading into increasing specialization), and restrictive desire to curb unsafe building and fraud. More complex building techniques required specialization. Although buildings became safer and cheaper to produce, a rigid system of organization dampened new innovation.

The breakdown of this system is now under way. Government-sponsored building research has pioneered new techniques, materials, and processes. Today a major impediment in overhauling construction methods is the failure to consider "externalities" such as handy transportation facilities, public utilities, and individual needs. "Technological change in housing must raise variety and quality, as sought by the occupants, and not merely lower cost, as defined by engineers." A recent study assessed the role that large American corporations might play in providing housing through mass production and found that institutional constraints limited technological response to the housing problem. Since housing is a stock, durability and maintenance are important areas for R & D. However, innovations must take into account who the occupants will be and where they are.

12. DIFFUSION OF INNOVATIONS PERSPECTIVES ON NATIONAL R & D ASSESSMENT: COMMUNICATIONS AND INNOVATION IN ORGANIZATIONS (E. M. ROGERS WITH J. D. EVELAND)

Organizations are an important part of modern society. Understanding the innovation process within them is crucial to understanding technological advance. A new "micro" approach to the study of innovation within organizations is proposed. The classical diffusion model is of limited value because of its implicit assumptions. It identifies the principal characteristics of innovation—relative advantage, compatibility, complexity, trialability, and observability—perceptual qualities that are easier to assess in an individual than in an organization. Adopter categories, which classify members of a social system, are based on the relative time at which adoption occurs; but they can be only applied to successful innovation. A measure for judging the value of proposed innovation is needed before a general theory is developed that can deal with failures as well as successes. The decision to adopt an innovation may be an individual's independent choice, a collective choice, or an authoritative decision. Problems arise in transferring the diffusion model from the individual level to the level of the organization. The adoption decision and its implementation may be two different subprocesses. Among the questionable assumptions of the classical diffusion model is the desirability of adoption. We must focus on how decisions are made, with what criteria, and with what consequences. The classical model considers cross-sectional data (comparative information gathered at a given time) as sufficient for evaluating organizational innovativeness, an assumption that ignores the continual change within organizations. Another assumption, that decisions are made by individuals, has led to studies of diffusion among organizations but not within them. We need a research style to facilitate a merger of organizational theory with the diffusion model. Large-survey studies on organizational innovativeness have identified variables but have not revealed how diffusion and innovation occur.

13. TECHNOLOGY FORECASTING LITERATURE: EMERGENCE AND IMPACT ON TECHNOLOGICAL INNOVATION (J. R. BRIGHT)

The importance of technology forecasting (TF) has grown with the increasing impact of technology on our environment. An increasingly rapid succession of improvements requires huge commitment of resources. Growing concern over the environment has prompted government to require impact studies of its major technological programs and has given rise to technology assessment. But assessment requires anticipation. Traditional forecasting, which relies on expert opinion, is no longer adequate with the growing complexity and interaction of technologies.

Technology forecasting is a qualified, logical prediction. Its objective nature and purpose distinguishes it from opinion and prophecy. The possibility of forecasting is supported by several rationales. General consistency or pattern in technological change provides a basis for trend extrapolation from past data. By choosing appropriate parameters one can extend past time series. Such projections can predict future levels of performance and capability. Technology is a response to needs and opportunities. Normative (goal-oriented) forecasting has arisen from growing willingness to provide public support for technology leading to desirable social goals. Careful consideration of future needs reveals the kind of technology that is desired and will probably be developed. Finally, by monitoring the process of innovation signals can be identified. Since innovation is a long process, most technological innovations are visible before they are widely available or applied.

14. TECHNOLOGICAL INNOVATION AND ECONOMIC GROWTH (SIMON KUZNETS)

The author has summarized his findings in nine points, given below largely in in his own words:

(1) Technological innovation played a key role in the rise of product and productivity in modern economic growth; and also induced major transformations of conditions of work and life.

(2) These transformation were required to channel new technology effectively, and meant organizational changes in the earlier institutions that governed production. The resulting changes in conditions of work for the active participants were a major element in changing conditions of life. Thus, technological innovations required innovations in social structure and even in prevailing attitudes. They also required adjustment to resulting displacement of resources in earlier, and obsolete, uses.

(3) A major technological innovation involves a sequence of phases stretching over a long life cycle. Of the four phases suggested—preconception, initial application (IA), diffusion (D), and slowdown and absolescence (SO)—the IA and D phases alone account, on the average, for half a century. The phase sequence, the differences in input-output relations in the several phases, and the phase differences in the interplays between the technological, economic, and social adjustments bear clearly on analysis, policy consideration, and prognosis.

(4) The clustering of even major technological innovations into groups of related changes (stemming from exploitation of one source of power, or from a new industrial material, or from the interrelation of functions within a production process), combined with the interplay between innovations and the social and institutional adjustments to them, lengthens the sequence of distinctive phases and adds to their complexity.

(5) The focus of technological innovations shifts over time from one sector of the economy to another, and creates new sectors. Their immediate impact is always unequal among sectors, and hence among social groups in the economy. This inequality of impact is itself a social and economic problem that requires adjustments.

(6) Because of the combination of conventional economic inputs with required changes in conditions of work and life, and because of the combination of conventional economic outputs with possible nonconventional byproducts of technologically induced economic growth, an adequate quantitative gauge of the *net* contribution of technological innovations to economic growth is still to be established. Current measures of total factor productivity, though possibly reflecting largely technological changes, are either limited to conventional input and output, or involve a variety of *ad hoc*, and not fully tested, assumptions as bases for inclusion of nonconventional inputs or byproducts.

(7) Such a net measure may not be of much value, since a variety of elements, in both inputs and outputs, is needed to give meaning to the comparison. Yet the search for such a net measure helps to focus the analysis. Provisionally, one may justifiably argue that the social valuation of technologically facilitated, modern, economic growth is high and positive, with the critical reaction reflecting responses to temporary lags in adjustment.

(8) Technologically induced economic growth, having been attained, stimulates further technological innovation. A particularly important stimulus is the learning that takes place through mass application of recent new technology and yields new data, new tools, new insights and puzzles to natural science, and helps widen the base provided by the latter to further technological breakthroughs and innovations.

(9) Economic growth hastens the maturity of the older fields by slowing down growth of final demand for their products. It may also limit the conditions for responsive innovative entrepreneurship in the established and modernized fields because of the large scale of the firm, and possible dominance of a few in an oligopolistic or monopolistic situation. Furthermore, the rise in the share of the public sector is a factor, since in its nonmilitary areas it may not be easily responsive to technological innovation. The slowing down of the older sectors, once modernized through technological innovation, helps to shift the focus of innovation to other sectors; such shifts help to maintain a high or increasing pace of technological innovation and of economic growth.

The economic consequences of technological innovation has been a neglected area. Economists have approached problems of economic growth with a short-term orientation in which "technology, institutions, and consumer tastes were all supposed to be given." A lack of data regarding the effects and origins of technological innovation is a consequence of the orientation. Effective policy action requires measurement and analysis of the quantitative aspects of technological impact. Work relating new quantitative data with established measures would be particularly useful. For example, distinguishing aspects of total output, labor force, and capital associated with recent and older technology would help relate technological innovation and economic growth.

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14. Langrish, J., and others. Wealth from knowledge. A study of innovation in industry. New York, John Wiley [1972], 490 pp.

These researchers from the University of Manchester studied the 84 innovations winning Queen's Awards in the U.K. in 1966–67. They found that the most important factor ensuring the success of an innovation was an outstanding technical manager, that weak markets were most important in delaying innovation, that demand pull was more important than discovery push, and that many of the crucial ideas necessary for innovation came from outside the firm (copyright permission not granted to reproduce original materials).

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15. Myers, Sumner, and Donald G. Marquis. Successful Industrial Innovations; a Study of Factors Underlying Innovation in Selected Firms. Prepared for the National Science Foundation under contracts NSF–C321 and C556. Washington, U.S. Govt. Print. Off., 1969. 117 pp. (NSF 69–17)

CHAPTER 7. PRINCIPAL FINDINGS AND IMPLICATIONS FOR MANAGEMENT

The process of innovation is "managed" at many levels. Individuals and groups at the working level in research and development, and marketing and manufacturing, are the major sources of new ideas and of solutions to problems. Technical competence, experience, and effective communication are critical for their success. Higher levels of corporate management are concerned with strategies for planning and evaluating the program of innovations, for allocating resources to laboratories and projects, and for policies and procedures to make the working groups more effective.

The findings of the present study are relevant to only some of the questions of management. The innovations examined were predominantly minor rather than major innovations—the technical changes that enable a firm to maintain itself in a competitive environment and to grow in some direction. In the following pages the principal general findings will be summarized and their implications for the management of innovation will be explored.

1. *Technical change is, to a significant extent, based on the cumulative effect of small, incremental innovations.*—Radical path-breaking innovations are relatively rare and quite unpredictable, whether they are based on science or on ingenious invention. In the present study two-thirds of the innovations cost less than $100,000 for their development to the point of use. One-fourth required little or no adaptation of information readily obtained from some source, and one-third were modifications of existing products or processes rather than new items. Almost one-half of the innovations required little or no change in the firms' production process.

Small incremental innovations thus contribute significantly to commercial success. From the standpoint of management this would call for sustained support of innovation activities to maintain the competence, experience and personal contacts of the professional technical staff.

2. *Recognition of demand is a more frequent factor in innovation than recognition of technical potential.*—The idea or concept for an innovation is necessarily a fusion of recognition of both demand and technical potential. In the present study the innovators indicated that the primary factor in undertaking work on the innovation was a recognized market potential or a recognized need in the production process in three-fourths of the cases. In 21 percent of the cases the primary factor was recognition of a technical potential which might be exploited.

The data of the present study concern relatively moderate innovations, but adoption may be even more important in major path-breaking innovations. Much has been written about the not-invented-here resistance to change. Since no firm can perform more than a very small proportion of the worldwide inventive activity in any area of technology, it follows that serious attention should be directed to technology outside the firm, and a deliberate trade-off choice should be made between being first or second.[1]

4. *Ideas for innovations may be evoked by new information inputs.*—In more than one-fourth of the innovations studied, an information input initiated active work on the problem. This finding underlines the importance of a receptive climate for new ideas which are not currently being worked on.

While this study did not seek systematic data on organizational response to new ideas, the sources and channels of information which generated ideas for successful innovations were obtained. Compared with the total set of innovations, the information inputs for idea generation were much more likely to be initiated by others, and in 30 percent of the cases were obtained through personal contacts external to the firm. Printed materials of all kinds were the source of only 7 percent of the cases. The procedures used by a firm to encourage idea generation can take account of these findings on information sources.

5. *The major information inputs which contributed to the solution of a problem already being worked on by the firm were predominantly general in nature and widely diffused and readily accessible.*—They were obtained in two-thirds of the cases from knowledge based on education and experience.

Analysis of the sources of information contributing to successful problem solving showed, in agreement with other studies, that printed materials were a major source of information in only 7 percent of the innovations, although they may have critically important in those instances.[2] Printed materials are much more frequently used in scientific activity than in the moderate engineering inventions and developments of this study.[3]

6. *Personal experience and personal contacts are the principal sources of information for successful innovations.*—Corollary to the preceding discussion of R&D activity is the finding that the principal information inputs for commercial innovations were personal experience and personal contacts (75 percent of the cases). The picture is essentially the same whatever the role of the information input However, internal sources of information were more frequently the source of original innovations and external sources more frequently of adopted innovations. Also, internal channels were relatively less frequent sources of information which evoked the basic idea as compared with information which helped solve the problem.

It may be concluded that competent people are the major resource for innovation. A primary responsibility of management is then the selection, development, retention and effective utilization of technical personnel, including the facilitation of personal contacts both inside and outside the organization.

7. Perhaps the most general overall implication of the findings is that the management of technical innovation is much more than the maintenance of an R&D laboratory which is productive in technical output. In this study only a small fraction (21 percent) of the successful innovations were based primarily on the recognition of technological potential. and for even fewer did the major information input evoking the idea or solving the problem involve experimentation or analysis in the firm's laboratory. The management of innovation is a corporate-wide task, and is too important to be left to any one specialized functional department. The R&D staff can make its full contribution to the total process of innovation not only by effective problem solving, but by building its competence, knowledge, and personal contacts to contribute to the generation of new ideas and to the evaluation of proposed adopted innovations. In this way it can participate fully in the overall corporate strategy for technical innovation.

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[1] The complex role of patents, licensing and industrial security has not been explored in the present study. The recent organization of the Licensing Executives Association affords opportunity for discussion of professional questions in this area.

[2] There are no comparable figures for chemical and pharmaceutical firms, in which indexed documents are probably much more valuable.

[3] D. G. Marquis and T. J. Allen, "Communication Patterns in Applied Technology," American *Psychologist* (1966), 21 :1052–1060.

16. Myers, Sumner, and Eldon E. Sweezy. Federal Incentives for Innovation: Why Innovations Falter and Fail, A Study of 200 Cases. Prepared for the National Science Foundation under contract NSF–C860. Denver, Denver Research Institute, 1976. 77 pp. (Report R 75–04)

FINDINGS: OBSTACLES TO INNOVATION

Most of the obstacles to innovations reported fit comfortably into one of five broad categories—the market, management, laws and regulations, capital, and technology. In other words, the primary factor blocking an innovation could be found in one of these areas. (Only nine reported obstacles had to be assigned to a "miscellaneous" category.) Within the general categories, however, certain definite subcategories were discernible. Many of the management problems were clearly matters of organization and staffing, and patent and antitrust laws were recognizable sub-groups in the broad area of laws and regulations.

With this classification, the market and management could clearly be identified as the principal areas in which blockages to innovation occur. The two factors accounted for over half the blocked innovations reported in the interviews. Of this number, a little over half were attributable to the market and just under half could be assigned to management. Perhaps surprisingly, considering the attention which has been paid to R&D as a factor in innovation, the area of technology offered the fewest obstacles identified in the study. Table IV gives the complete breakdown by factor.

PERCENTAGE OF INNOVATIONS BLOCKED BY PRIMARY FACTOR

Primary factor blocking innovation	Innovations blocked	Percent of total
Market	55	27.5
Management (including organization)	47	23.5
Laws and regulations (including patent and antitrust)	35	17.5
Capital	31	15.5
Technology	23	11.5
Miscellaneous	9	4.5
Total	200	100.)

It is apparent that a large share of the obstacles to industrial innovation are less susceptible to direct government action—just about two-thirds of them, to be exact. Of course, the categories are very broad, so that government action might be able to affect *specific aspects* of a field *generally* beyond its reach.

The point should be kept in mind because, within the major obstacle categories (including organization, patents and antitrust as major), specific obstacles often stand out as particularly important.

The chief *market* problem for the producer's goods industrial segment was limited sales potential for proposed innovations, including public interest innovations; this accounted for over one-quarter of the market obstacles cited. Only five of the 55 innovations blocked by the market fell victim to the company's inability to aggregate a fragmented market for them. This figure seems remarkably low. However, it probably understates the negative influence of fragmented markets; innovations are not funded at all and never enter the pipeline if it is obvious at the outset that a market cannot be aggregated for them. Similarly, the effects of competition also may be understated; only four innovations were blocked because there were too many competitors in the market. Here, too, the obvious problem of entering an already crowded field would block innovation at the outset. The effects of competition manifested themselves with respect to technology: in fully one-quarter of the innovations blocked for technological reasons, the problem was that some other firm had come up with a competitively superior technical approach.

The analysis of management problems was discussed at the beginning of this section. As noted there, organization and staffing and market analysis failures were the most significant components in this category.

The *capital* problem was manifested more or less evenly among a number of specific obstacles, including the high cost of pilot production and changeover, insufficient resources, and opportunity costs. Only one innovation was blocked because of insufficient capital to develop a high-risk market. Again, this low number may reflect the existence of a preemptive, pre-pipeline blockage.

As for the *regulatory* area, the most striking finding was that the uncertainty of federal requirements, rather than their stringency, was perceived as the most important blocking factor. Only one innovation bowed to the length and cost of federal tests. Interstate variability of regulations is of marked importance. Many respondents complained about both patent and antitrust laws. But, in fact, both areas presented relatively few obstacles. Regulations blocked 2.5 percent of the innovations, and patents 3 percent. Here again, the figures probably understate the severity of the problems. Innovations that are obviously in violation of antitrust regulations don't get funded. Similarly, innovations with obvious patent problems are rejected at the outset. Finally, union opposition, listed in the miscellaneous category, was found to be a negligible factor, being mentioned twice in 200 innovations. In both cases, the anticipated union opposition was in the customer's company, not the innovating firms.

As noted earlier, in about one-fourth of the cases, the respondents cited a *secondary reason* for an innovation blockage in addition to the primary reason. In general, no particular pattern emerges in the linkage of primary and secondary factors. The market and capital were the two most frequently cited secondary reasons for innovative failure, but the numbers involved are too small for any real conclusions to be drawn. The remaining findings in the study are accordingly based on an analysis of primary factors alone.

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17. National Academy of Sciences. Applied Science and Technological Progress: A Report to the Committee on Science and Astronautics of the U.S. House of Representatives. Washington, U.S. Govt. Print. Off., 1967. 443 pp.

Conclusions and Recommendations

Group I. With Respect to the Nature and Strategy of Applied Research

1. THE INTERACTION BETWEEN SCIENCE AND TECHNOLOGY IS COMPLEX

In examining examples of the successful translation of science into technology, one is struck by the diversity of successful patterns and organizational structures. There are no simple formulas for success, and for this reason success is most likely when laboratory management has wide latitude in adapting and restructuring the organization to suit the particular problem areas or technologies with which it is currently dealing. Despite this need for administrative flexibility, it is possible to identify certain characteristics of the research environment that facilitate transfer of new scientific results to useful applications and fruitful feedback from applications to science. They include the following:

(*a*) The key individuals in the research organization are fully aware of and sympathetic to the principal goals of the organization, but at the same time the research mission is defined in broad-enough terms so that it retains its validity as circumstances and the state of technology change.

(*b*) The organization is willing to consider and implement new ideas or initiatives on their own merits regardless of the organizational level or functional subdivision in which they originate, or even if they come from a source outside the organization.

(*c*) People within the organization are receptive to moving between the more fundamental and the more applied activities, and also to changing specialties or scientific disciplines. The artificial barriers that sometimes exist between disciplines and between fundamental and applied work are minimized.

(*d*) The organization has a quick response in recognizing and funding new ideas, at least up to the point where the feasibility and desirability of a larger commitment can be assessed.

(*e*) At each organizational level the individual responsible has some freedom in redeploying the resources at his disposal without extensive review by higher authority. This is, of course, more true in research than in development, where the necessity of fitting into a system plan is important.

(*f*) There is full communication through all stages of the research and development process from original research to ultimate application. A good deal of overlapping activity between each of the stages is present.

(*g*) The system of reward and recognition emphasizes technical contributions to the goals of the organization, if necessary in preference to proper organizational behavior.

2. A BROAD SPECTRUM OF SCIENTIFIC DISCIPLINES AND TECHNICAL SKILLS IS REQUIRED

To an increasing degree the advance of technology requires contributions from a variety of scientific and technical fields. This fact imposes the necessity not only for effective communication within the research organization itself but also interaction with contemporary work in science and technology outside. The purpose of an effective research organization is to ensure the maximum possible opportunity for matching "problems" to "solutions"—the latter possibly coming from apparently little-related fields. The pattern of technical communications will not always, or even usually, reflect the organization chart.

3. THE TRANSFER OF TECHNOLOGY FROM THE LABORATORY TO A PRODUCING OR OPERATING ORGANIZATION WHICH BUILDS, SELLS, OR USES IT, IS A VITAL AND OFTEN UNDERESTIMATED STEP IN TECHOLOGICAL INNOVATION

In industry the using component may be a manufacturing organization, but often involves the final customer as well. In Government the using component may be an operating organization such as a military service, or a service agency such as the Weather Bureau. Often the user, as in agriculture or public health or physical standards, is in both the private and the public sector. The transition from developed technology to usable product, service, or public action is a well-known problem area, in which promising developments often falter or even founder. Effective transfer of each technical advance tends to be a unique problem, requiring a special approach tailored to the specific characteristics of both the research component and the using components or customers. The transfer process requires explicit attention very early in the development process as soon as some probability of *technical* success becomes apparent. It is well established that the best way to transfer some new types of technology is through the movement of knowledgeable people, either temporarily or permanently. It may be necessary, for example, for the originator of an idea to himself follow his brainchild into development, testing, or final production or utilization. Or, alternatively, operating people may have to be brought into the laboratory temporarily to learn the new technology early and to influence its development from the user standpoint.

4. GOALS IN APPLIED RESEARCH ARE REACHED ONLY BY REDUCING THEM TO A SERIES OF RESEARCHABLE, RELEVANT COMPONENTS, BUT THIS IS A DYNAMIC PROCESS, SUBJECT TO CONTINUAL REVIEW AS NEW RESULTS EMERGE

In establishing a viable program of applied research it is not sufficient to identify broad problems such as pollution or urban design. Rather it is essential within such broadly stated problem areas to identify the specific questions to which it appears feasible to obtain meaningful answers. The determination of technical approaches must be done by technical people, and the input of technical information to the decision process should come as directly as possible from the people who are actually doing the work, regardless of their position in the organization. Technical information filtered through multiple levels of reporting to the top tends to lose its integrity, ofen resulting in poor decisions.

On the other hand, the setting of research goals and priorities especially in the public sector is a task that requires a many-sided interaction between scientists, technologists, public officials, and informed public opinion. Such goals can neither be imposed by society unilaterally on the scientists nor determined by technical considerations alone. In the mobilization of technical effort around significant problems of society, it must be borne in mind that the highest-quality technical people cannot be drawn into projects solely on the basis of the alleged social importance of the problems. They must also be able to see an opportunity for making concrete, identifiable contributions that relate to their particular talents and background.

Group II. With Respect to the Environment and Institutions of Applied Research

1. SUCCESSFUL AND RELEVANT APPLIED RESEARCH IS MOST OFTEN CARRIED OUT BY COHERENT INSTITUTIONS

The setting of sensible and realistic goals for applied research projects is usually done most successfully in close interaction with systems engineering or analysis. Systems studies that take into account all phases of a problem, and research aimed at exploring feasibility, must interact and reinforce each other. In many successful technical devlopments, there is a continuing three-way interaction between the changing concept of a system, the development of its components, and the evolving understanding of the environment in which it is to operate. This is true not only for engineering systems, but also for "systems" such as medical care, education, or transportation, in which physical components interact with social environments. The implication of the above considerations is that the guidance of applied research, unlike that of basic research, requires an institutional environment that is capable of dealing with all facets of a problem in a coherent fashion, developing a "coherent doctrine" into which the various subsidiary research goals can be fitted in a logical fashion. An applied research program administered by a headquarters staff distributing small sub-tasks among many participants is seldom as effective as a laboratory that assumes full responsibility for a major problem area.

2. COMMUNICATIONS BARRIERS IMPOSED BY SECURITY OR OTHER REQUIREMENTS REDUCE THE PRODUCTIVITY OF APPLIED RESEARCH

Applied research, like basic research, thrives in an atmosphere of free exchange of ideas and maximum exposure to scientific criticism. While security restrictions or compartmentalization for proprietary reasons are sometimes necessary, it is important to recognize that they exact a substantial price in loss of effectiveness in the research effort. Too often security or "need-to-know" restrictions serve only to protect inadequate or ineffective work from critical scrutiny by a larger technical community. Such restrictions should be imposed only for the most urgent reasons, and should be constantly reviewed to determine whether the gains are worth the cost.

3. APPLIED RESEARCH ORGANIZATIONS SHOULD INTERACT WITH UNIVERSITIES WHEREVER POSSIBLE

In planning for the creation or development of mission-oriented research institutions, consideration should be given to facilitating interaction with universities. For Government-owned laboratories, interaction with industry in similar lines of work is also important. The mission-oriented laboratory benefits from new ideas and viewpoints brought in by outside scientists, while the university community is stimulated by contact with problems of application, which often trigger new lines of fundamental research. Applied research and development people should have opportnuities to teach and to come into contact with graduate students, recognizing that any temporary loss of productivity will be more than compensated by the long-term benefits of the exposure of able students to the intellectual challenge of applied research.

Group III. With Respect to the Individuals Who Conduct Applied Research

1. APPLIED RESEARCH REQUIRES PERSONAL MOBILITY

Since the transfer of technology and the applications of new science frequently occur through the movement of people among different kinds of scientific activities and institutions, policies for the support of research should always be considered in light of the need to foster such mobility and to reduce organizational and intellectual barriers between basic and applied research, between Government, universities, and industry, and between different fields of science. Many foreign observers cite the mobility of scientists among institutions and disciplines in the United States as a major factor in our superior performance in the application of science. It is important that in our desire to protect the integrity and objectivity of basic science we do not discourage this important type of mobility.

2. THE UNIVERSITY PLAYS A CRUCIAL ROLE IN THE EDUCATION OF PEOPLE FOR APPLIED RESEARCH

The highest-quality applied work is often done in an environment in which a substantial pool of people with original training in basic sciences can be drawn upon for applied research and development activities, especially as these people broaden and mature in experience. Thus it is desirable and natural that the educational system should produce an excess of people trained at the research frontiers of science and engineering over those required to feed back into the educational system itself. Not every student trained in basic research should expect to have a long-term career in fundamental science. Too frequently, however, the general climate in universities and professional societies tends to denigrate the intellectual challenge and satisfaction of applied research; in discovering these things for himself, a scientist or even a research-trained engineer must often overcome adverse attitudes fostered by his graduate studies and professional associations. A greater effort should be made to create an atmosphere in graduate education that would anticipate and encourage the subsequent entry of many students into applied work. Although this problem is less acute in the professional schools—especially in medicine—it is not unknown even in this area.

3. THE TECHNICAL ENTREPRENEUR IS FREQUENTLY THE CATALYST OF PROGRESS

The technical entrepreneur, or missionary—the man who carries the torch for a new idea—is often the catalyst of technical progress. Even though he may sometimes be more distinguished for enthusiasm and ingenuity than for profound technical understanding, his courage and tenacity are frequently vital elements of successful innovation. We need to identify such individuals early in their careers, to encourage appropriate educational preparation, and to ensure an occupational environment that will enhance their contributions.

It must be recognized, however, that many successful innovations have been accomplished without such zealots. Some very able and original technical people who have contributed important innovations, are not especially vocal or persuasive. Infectious enthusiasm may impart courage when—as is frequently the case—courage is needed; but enthusiasm will not, of course, repeal a law of nature, if that is the roadblock that stands in the way of a successful innovation. The technical idea that has glamor or popular appeal or is easily explained and dramatized is not always the best idea, or the one most likely to lead to successful application in the long run.

Group IV. With Respect to the Role of the Federal Government in Applied Research

1. APPLIED RESEARCH ESTABLISHMENTS OF THE FEDERAL GOVERNMENT SHOULD BE EXAMINED FOR REDEPLOYMENT IN THE LIGHT OF CHANGING NATIONAL NEEDS

The large interdisciplinary applied research establishments of agencies of the Federal Government comprise an important national resource. Although many of these laboratories were founded upon a specialized scientific or technical field with major mission orientation, by virtue of their scientific breadth they now have impressive and versatile capabilities. In addition to their fields of origin, they undoubtedly could perform with great effectiveness in a variety of contemporary scientific fields, some within the purviews of Government agencies other than their original parent organizations. The programs and organizational locations of Federal laboratories should therefore be examined at appropriate intervals to determine whether the maturity of their original missions would justify some reassignment of effort to emerging problems of challenging national interest. New national missions or regrouping of old missions often become possible as a result within science and technology themselves. Thus redefinition of agency purposes is essential for exploiting such developments in in a timely effective way and realizing the maximum benefits from prior investments in science.

2. PATENTS PLAY A VITAL ROLE IN UTILIZING THE RESULTS OF APPLIED RESEARCH

In modern industry, in which useful economic innovation is sought as a source of growth, patent protection is almost always essential to successful useful application. The originator of a new process, product, or service generally cannot risk the very considerable investment in production equipment or in exploring and developing a market if his competitor is free to copy his invention and use it without paying for the development. A very large fraction of the industrial applied research now in progress in this country would not be justified in the absence of potential patent protection, or would have to be accomplished under tight industrial secrecy. The widespread practice of promptly publishing scientific and technical results originating in industry could not exist without patent protection. Patents are thus the antidote for both the pirating of ideas and the maintenance of secrecy.

3. STUDIES OF THE HISTORY AND SOCIOLOGY OF APPLIED SCIENCE ARE IMPORTANT

Studies of the history and sociology of science and technology should be encouraged, in order to further understanding of the principles behind the great variety of successful patterns of applied research and its transfer. To be effective, such studies probably require the participation of both natural scientists or technologists and social scientists or historians. Both academic studies and retrospective self-studies within research organizations are desirable, but the complexity of the subject must be recognized and premature generalizations and policy application avoided.

4. WHEN POSSIBLE, FORECAST TECHNOLOGICAL PROGRESS

The effort at technological forecasting—that is, projecting future technological possibilities and probabilities in relation to current knowledge and research and in relation to potential interactions with society, with the economy, and with the natural environment—can provide important guides to the identification of new goals for applied research, and in educating and alerting scientists and technologists to new possibilities. Technological forecasting is, however, a relatively new field and its methods are subject to further improvement. It can do more harm than good for research planning if its results are treated as more than rough first approximations. Part of the purpose of research is to keep many future options open to society, and the purpose of technological forecasting is primarily to identify and expand these options rather than to foreclose them.

5. CONCERN WITH THE ENVIRONMENT MUST BE A GROWING FEDERAL RESPONSIBILITY

Understanding, prediction, and control of the consequences of technology, industrialization, and urbanization on man's physical and biological environment are urgent. A broader and more intensive national effort is needed on the integrity and sufficiency of the environment. This effort must also encompass the logical constraints that are placed on the quantity and possible quality of life, and hence on wise social development, by the availability and quality of natural resources.

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18. National Academy of Sciences. Technology, Trade, and the U.S. Economy. Washington, 1978. 180 pp.

ABSTRACT OF ISSUES AND RECOMMENDATIONS

The choice of the designation abstract rather than summary is deliberate. The report itself is in essence a summary—not a study in the usual sense, but an analytical and interpretative summary of 10 days of workshop discussion. The workshop brought together 39 individuals of diverse backgrounds to discuss a broad and complex tangle of issues relating to technology, international trade, and international investment and their implications for the U.S. economy. The discussants came from private industry, organized labor, departments and agencies of the federal government, universities, private research organizations, and, in one instance, an international organization. Their training and experience included the natural sciences, engineering, management, economics, government, law, and the crafts.

The issues and recommendations that follow are grouped to correspond to the main sectors of our inquiry. The OECD sector of the discussion exposed not only issues of particular application within the OECD group itelf but also issues of general significance and application to U.S. trade with all countries.

ISSUES AND RECOMMENDATIONS OF GENERAL APPLICATION

The search for causes and the attempt to appraise the consequences were related to the primary mission of the workshop: to assess the importance of technological factors on trade and to discover and explore possible remedial policies and actions, if they were called for. While the many differences in approach and analysis among the participants led, inevitably, to differences in proposals for action, the participants did agree on certain suggested measures. The two most important are as follows:

The U.S. government should not enact legislation to restrain the export of commercial technology by private firms from the United States (apart from possible special measures designed to meet special problems as they arise, for example, in trade with the Soviet Union).

A general inquiry should be organized into all possible ways and means to foster technological innovation in the United States. This inquiry should range broadly over tax policy and incentives, regulatory policy, antitrust practices, and other federal laws and policies affecting innovation.

Two additional conclusions were specific in nature:

The U.S. government should adjust its priorities in the allocation of financial support to research and education, by giving enhanced attention to research and education affecting productivity and innovation in commercial technology and by seeking effective ways to provide financial support to research in process engineering and production systems and to imaginative engineering training related to the processes of production. This adjustment should and could be made while federal support for basic research is fully maintained or, indeed, increased.

An inquiry should be undertaken into the comparative age and quality of the stocks of capital goods, arranged by industrial sectors, within the United States and other countries. Such a study should emphasize comparison of U.S. industries with those in other countries in the OECD.

ISSUES AND RECOMMENDATIONS CONCERNING TECHNOLOGY TRANSFER, TRADE, AND INVESTMENT AMONG THE OECD COUNTRIES

The issues and recommendations in the preceding section are relevant to relations among the United States and the other OECD nations, as well as to relations of the United States with countries outside the OECD community. Another set of issues and recommendations has a special bearing upon technology transfers, trade, and investment within the OECD. What have been the domestic economic costs and international competitive implications of certain U.S. regulatory legislation designed to serve such valid and varied purposes as environmental protection, occupational and personal health and safety, public participation in decisions of public concern, and protection against undue financial or corporate concentration? In the enactment of such legislation and in its administration, have the economic costs and international competitive implications been adequately factored into the total cost-benefit analysis? The workshop discussants expressed concern over the international competitive consequences of differences in the nature, scope, and vigor of regulatory policies among the several nations in the OECD and asked whether the consequences of such policies give a new thrust for harmonizing economic policies among the OECD nations. Was it necessary and would it be feasible to consider such a new harmony not only of macroeconomic but also of microeconomic policies?

ISSUES AND RECOMMENDATIONS CONCERNING THE EFFECT OF TECHNOLOGY TRANSFER UPON U.S. LABOR

In the view of the workshop participants from organized labor, the transfer of U.S. technology abroad and more especially the transfer of entire plants and production systems has had mounting adverse effects upon employment within the United States. In their view, the provisions for adjustment assistance under existing U.S. trade legislation are woefully inadequate to remedy the unemployment and dislocations that have been attributed to technology transfers to other countries. They raised the issue of direct governmental control over the transfer abroad of U.S. technology by U.S. enterprises. In advocating direct controls, they insist that U.S. labor is not turning protectionist or abandoning its support of legislation to foster international trade. They described several of the possible causes of technology transfer: the barriers to free trade interposed by foreign governments and foreign governmental subsidies to their own enterprises, the flight by some U.S. firms from social and environmental regulatory measures at home to countries where comparable legislation is less or lacking: and the U.S. government's encouragement of the export of technology by American firms for foreign policy reasons wholly unrelated to economic considerations. They also pointed to tax legislation that allegedly facilitates the export of technology. In their view, the "market" has very little to do with the phenomenon. As a consequence, they consider that remedial governmental measures to restrain the export of technology, along with capital and jobs, would be fair, reasonable, and beneficial to the nation.

The members of the workshop generally acknowledged the problem and sympathized with the plight of labor; however, they rejected proposals for additional U.S. governmental restraints upon direct foreign investment and technology transfer by U.S. enterprises. The majority of the participants favored other measures:

The existing readjustment assistance legislation should be amended to expand the scope of eligibility for assistance by including workers who are laid off because the employer has transferred operations to another country or whose jobs are indirectly jeopardized by imports; to extend the time limits during which benefits would be made available; to simplify procedures; and to expand and strengthen job retraining programs.

Whenever the federal government may be disposed to sponor the transfer of advanced U.S. technology for foreign policy reasons (for example, in bilateral agreements with other nations), full account should be taken of domestic economic considerations and consequences, including the possible effects upon domestic employment, before a decision to transfer the technology is reached.

The United States should adopt and seek to give effect to a principle of "tax neutrality" in regard to direct investment and technology transfer abroad by U.S. firms (i.e., taxation considerations should create neither an incentive nor a disincentive for the U.S. investor to invest abroad). Aware of the complexities and difficulties of carrying out such a policy, the participants believe nevertheless that a sustained effort should be made.

ISSUES AND RECOMMENDATIONS RELATING TO TRADE, INVESTMENT, AND TECHNOLOGY TRANSFER BETWEEN THE UNITED STATES (AND OTHER OECD COUNTRIES) AND THE SOVIET UNION (AND OTHER EAST EUROPEAN COUNTRIES)

Two sets of questions dominated the workshop discussion of technology transfer in trade with the Soviet Union. How can and should U.S. institutions and patterns of trade, investment, and technology transfer be adapted to problems arising from national security considerations? What are the actual and potential costs and benefits for the United States of trade with the Soviet Union?

The discussion ranged through a number of subsidiary questions, with emphasis upon problems relating to governmental controls. What degree of control should be exercised by the federal government on the transfer of technology? What materials, goods, and skills need to be controlled? How appropriate and effective are the mechanisms for such control? What are the likely international implications of attempts to control trade in goods and services available from many nations besides the U.S.?

A consensus was reached by the participants on the importance of coordination among the OECD nations that are major sources of technology for the Soviet Union. Such coordination should cover principles and operational guidelines as well as procedures for assuring compliance with agreed principles and guidelines. There was consensus that there was little point in controlling sales that transferred technology if the same technology is available from non-U.S. sources that place no restrictions on such sales. The force of this recommendation was reduced somewhat by doubts among the participants on the efficiency of existing and prospective bureaucratic controls and concern for the costs of controls, even if and when they could be made efficient. The same doubts were raised about domestic controls.

There was also agreement that the control of sales of "militarily sensitive technology" should be keyed to "lead time" criteria. There should be a presumption against authorizing sales to the Soviet Union of militarily sensitive technologies in which the United States holds a significant lead time advantage. Conversely, there would be little point in restricting sales to the Soviet Union of technologies in which the United States has only a negligible lead time advantage.

The participants stress the need for more insight into problems of accommodation between the respective institutions of the United States and the Soviet Union that determine patterns for trade, investment, and technology transfer. In the members' view, there has been a tendency among OECD governments, business enterprises, and scholars to pass too lightly over the institutional differences and their possible consequences. As trade increases between the United States (and OECD nations generally) and the Soviet Union, the United States (and other OECD countries) might be confronted with a choice between serious impairment of their own comparatively open trading and payment systems and a blunting and reversal of the expansion of trade with the Soviet Union. These participants had no solutions to offer to the problem they defined, but they urge that more attention be given to the problem.

ISSUES AND RECOMMENDATIONS CONCERNING TECHNOLOGY IN DEVELOPING COUNTRIES

The discussion of technology transfer to developing countries centered upon the demands of the Group of 77 [1] for modes of technology transfer appropriate to the New International Economic Order. In a sense, this added a new thrust to the workshop inquiry, as the scope of the workshop was enlarged from an assessment of harms and benefits to the United States to an assessment of benefits and harms to the developing countries as perceived and articulated by their spokesmen, notably the Group of 77. In another sense, however, the workshop maintained its original direction and emphasis but interpreted "effects upon the United States" in terms of the nation's foreign policy as well as its foreign trade position and domestic economy.

Examination of this issue began with a review of arguments voiced by the group of 77 against present technology transfers—that the cost of technology transferred to the developing countries through direct foreign investment by multinational corporations is unwarrantedly high; that the technology transferred is not suited to the special capacities and needs of the recipients; and that multinational corporations engage in unfair practices that discourage the rise and development of local enterprises. Many of the workshop participants believe the assertions to be unfounded or exaggerated and significant primarily as reflections of the Group of 77's aspirations and frustrations. The discussion turned to possible ways and means by which the United States might accommodate its policies in some measure toward relief of the frustrations and support for the aspirations.

In the end, the workshop recommended that

A program be established by the National Science Foundation or other appropriate government agencies to carry out a continuing analysis of ways and means by which the United States could respond to the desire of the developing countries for technology appropriate to their needs and capacities.

The United States consider plans to assist financially the establishment within developing countries of regional institutions of applied research and development (R&D), as well as the creation of international institutions designed to contribute to understanding of the industrialization and economic development process in developing countries. Several participants warned that the usefulness of regional institutions would depend on how effectively the work could be assimilated into the outlook and practice of local enterprises that were expected to use the R&D results in production.

The United States explore possible new programs (or seek to improve existing programs) that would (1) assemble and maintain inventories of technologies the federal government owns or has legal capacity to transfer and (2) facilitate the selective transfer of such technologies to developing countries.

The United States cooperate with other OCED nations in coordinated programs for the selective transfer to developing countries of technologies that OECD governments own or have legal capacity to transfer.

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[1] Historically, the Group of 77 is that informal association of developing nations which came into existence at the 1964 United Nations Conference on Trade and Development (UNCTAD) and pressed the industrialized nations for a new international economic order. The Group of 77 now comprises 111 member countries of the United Nations.

19. National Academy of Sciences. National Research Council. Materials Advisory Board. Report of the Ad Hoc Committee on Principles of Research-Engineering Interaction. Washington, 1966. Various pagings. (Publication MAB-222-M) [Available from the National Technical Information Service, No. AD 636 529].

ABSTRACT

The evolution of 10 separate material developments were investigated and case histories are presented.

A technique of analysis was developed and applied to the case histories to identify common elements and patterns which might be used as guides by the Department of Defense to stimulate research-engineering interactions in the solution of materials problems. The analysis identified several elements which were prominent in many of the cases. Among these are:

(1) Flexibility for the individual investigators to make major changes in direction and goals was frequently required.
(2) Close and frequent communications between organizationally independent groups were often essential.
(3) Key individuals played essential roles in bridging the geographical, organizational, and functional barriers between groups.
(4) The recognition of an important need was most frequently the principal factor in stimulating research-engineering interactions.
(5) Often technical approaches were available and lay dormant for some time before their pertinence to a specific need was recognized.

Findings

GENERAL FINDINGS

The factors that are most commonly identified in the discussion of the cases can be classified into three main groups.

1. Characteristics of the environment in which the events took place, such as type of institution, its organization and communication patterns, management involvement, nature of the support, organizational traditions, etc.

2. Characteristics of the individuals involved in the events, such as educational level, basic or applied training and interests, etc.

3. Characteristics of the problem itself, such as technical difficulties, the visible need for a solution, etc.

These findings are presented below and underlined for emphasis.

CHARACTERISTICS OF THE ENVIRONMENT

Two of the three most commonly identified factors in the cases concerned the environment in which the events took place. One of these was related to the support of the activity. The second was related to the role of communications during the events.

In eight of the ten cases the authors observed that the flexibility of support was critical to the final success. In these cases the majority of the REI events required the ability to shift direction and explore unanticipated paths. This was readily done because the support was on a broad enough base to permit adequate discretion on the part of the investigators. In the remaining two cases the flexibility of support was important in at least one of the critical events, although it was not identified in the majority of the events. In these cases it was most frequently identified as important in the REI events which occurred in the first three stages.

It is, however , necessary to qualify this finding in view of its relation to other findings of the study that are discussed below. Indeed, each of our separate findings must be considered in the context of all of the findings. Thus it is noted below that the recognition of a need characterized most of our cases. Therefore, the flexibility to which we refer above generally operated in an environment that was structured by the recognition of a need. This, of course, moderates the degree of flexibility which was exercised.

In nine of the ten cases the majority of the identified events required close and frequent communications between organizationally independent groups. In many cases these groups were geographically separated and had different functional responsibilities (e.g., basic research vs. development). In eight of the cases geography was very infrequently cited as a significant factor. This latter finding at first seems at variance with the identified importance of communications. On the other hand, close examination of these latter cases showed that in every instance there were one or two key individuals who, through their efforts, bridged the geographical, organizational, and functional gaps; actively stimulated communications; and sometimes performed the technical work which was a vital part of the REI. These key individuals are the people whom we will refer to as "couplers."

Other environmental factors such as the role of management, the type of organization (government, commercial, university, nonprofit, etc.), organizational structure, research and development traditions, etc. are variously cited as important in about half of the total REI events. Thus one might conclude that in these cases these factors played important but not crucial roles. This observation is, of course, based upon an assumption that applies to the entire analysis; namely, that each of the events had the same significance to the over-all achievement. Indeed, it may well be that these factors played a crucial role in the most critical event in a given case. The present method of analysis would not identify that situation. Indeed in retrospect, the Committee has recognized that our study did not probe deeply into these other environmental factors. We recognize this as a major weakness in our efforts and we will refer to this later.

CHARACTERISTICS OF THE INDIVIDUAL

Many of the cases include biographical sketches of, or comments about, the principal individuals who were invloved in the critical events. In every case an individual with postgraduate (often doctoral) education was invloved in at least one of the events. In about half of the cases most of the events revolved about individuals with formal postgraduate academic training.

In several cases an individual emerged whom we will define as a "champion." This is an individual who becomes intensely interested and involved with the over-all objectives and goals and who plays a dominant role in many of the REI events through some of the stages, overcoming technical and organizational obstacles and pulling the effort through to its final achievement by the sheer force of his will and energy. We have selected the word "champion" to indicate an individual whose extensive energies were focused upon a single goal with single-minded purpose. We do not intend any value judgment in the use of this term and leave such judgments to the reader in each individual case.

CHARACTERISTICS OF THE PROBLEM

One of the most enlightening aspects of the analyses was the manner in which the character of the problem itself appeared to affect the frequency and intensity of research-engineering interactions. In all but one of the cases studied, the recognition of an important need was identified in a majority of the events as an important factor in bringing about the research-engineering interaction. It was very rare that basic research by itself produced a new and unexpected opportunity which then stimulated a search for engineering application. By far the most dominant mode was the case where an urgent need stimulated a search for solution through prior basic knowledge. This seems to substantiate the simile of research as a well of knowedge from which engineering can drink to satisfy defined needs rather than as a geyser which floods the engineer with solutions to present problems and with clear opportunities for exploitation.

This observation aslo qualifies the type of communication exchange which was discussed in the section on environment. In almost all of the cases under consideration, it was an individual with a well-defined need who was the initiator of the communications. It was most frequently he who began the dialogue with the basic researchers and determined its continuation until the need was satisfied. If this generalization is valid, then it is perhaps most important for the individual on the applications side to be able to look across the interface to basic research and know when to initiate the dialogue.

Finally, although in all cases technical problems were encountered and overcome, in only four of the cases did a majority of events require the development of a new solution to a major technical problem. In many instances, it appeared that technical approaches were available but had not been pursued, and it was the act of timely recognition, bringing available knowledge to bear on the problem, that resulted in the final solution. This leads to the suggestion that there is much knowledge in the well of research which has yet to be tested, tried, and applied in the solution of current critical problems.

The factors cited above have been emphasized because their presence or absence was particularly striking to the Committee in reviewing the case histories. It must be repeated that some of the cases emphasized additional factors and that there are many factors which might have been of critical importance but which the limitations of our study did not permit us to investigate. We stress again that it is particularly dangerous to draw broad generalizations based upon these very imperfect analyses. We must repeat that a principal characteristic of this study has been the large heterogeneity of the environments, personalities and problems which fill our case histories. We believe that the greatest benefits are to be derived by a study of the individual cases themselves and by the individual analysis of this report by each reader.

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20. **National Commission on Technology, Automation, and Economic Progress. Technology and the American Economy. Washington, U.S. Govt. Print. Off., 1966. 115 pp.**

SUMMARY OF MAJOR CONCLUSIONS AND RECOMMENDATIONS

The issues discussed in this report are complex and diverse. A brief summary of major conclusions cannot do justice to the report and is certainly not a substitute for the full text with its supporting evidence and argument. Once the text has been read, however, a summary may serve a useful purpose in crystallizing the major points and pointing up the recommendations which have been made. The principal conclusions and recommendations follow:

1. There has been some increase in the pace of technological change. The most useful measure of this increase for policy purposes is the annual growth of output per man-hour in the private economy. If 1947 is chosen as a dividing point, the trend rate of increase from 1909 to that date was 2 percent per year: from 1947 to 1965 it was 3.2 percent per year. This is a substantial increase, but there has not been and there is no evidence that there will be in the decade ahead an acceleration in technological change more rapid than the growth of demand can offset, given adequate public policies.

2. The excessive unemployment following the Korean war. only now beginning to abate, was the result of an economic growth rate too slow to offset the combined impact of productivity increase (measured in output per man-hour) and a growing labor force.

3. Since productivity is the primary source of our high standard of living and opportunity must be provided to those of the population who choose to enter the labor force, the growth of demand must assume the blame for and provide the answer to unemployment. But it must be realized that the growth rate required to match rising productivity and labor force growth rates is unprecedented in our history, though not in the history of other industrial economies. There will be a continuing need for aggressive fiscal and monetary policies to stimulate growth.

4. To say that technological change does not bear major responsibility for the general level of unemployment is not to deny the role of technological change in the unemployment of particular persons in particular occupations, industries, and locations. Economic and technological changes have caused and will continue to cause displacement throughout the economy. Technological change, along with other changes. determines who will be displaced. The rate at which output grows in the total economy determines the total level of unemployment and how long those who become unemployed remain unemployed, as well as how difficult it is for new entrants to the labor force to find employment.

5. Unemployment tends to be concentrated among those workers with little education, not primarily because technological developments are changing the nature of jobs. but because the uneducated are at the "back of the line" in the competition for jobs. Education, in part, determines the employability and productivity of the individual, the adaptability of the labor force, the growth and vitality of the economy, and the quality of the society. But we need not await the slow process of education to solve the problem of unemployment.

6. The outlook for employment and adjustment to change in the next decade depends upon the policies followed. Uneven growth and decline of occupations and industries could, but need not, cause serious difficulties for the economy as a whole. The number of unskilled jobs will not decline, though unskilled jobs will continue to as a proportion of all jobs. Growth patterns in both the economy and the labor force provide an important warning: Unless Negroes

and, to a lesser degree, youth, are able to penetrate growing occupations and industries at a more rapid rate than in the past, their high unemployment rates will continue or even rise. Our society must do a far better job than it has in the past of assuring that the burdens of changes beneficial to society as a whole are not borne disproportionately by some individuals.

7. The more adequate fiscal policies of the past 2 years have proven their ability to lower unemployment despite continued technological change and labor force growth. Economic policy must continue, watchfully but resolutely, to reduce the general unemployment rate. We must never again present the spectacle of wartime prosperity and peacetime unemployment. The needs of our society are such that we should give major attention in our fiscal policies to public investment expenditures.

8. With the best of fiscal and monetary policies, there will always be those handicapped in the competition for jobs by lack of education, skill, or experience or because of discrimination. The needs of our society provide ample opportunities to fulfill the promise of the Employment Act of 1946: "a job for all those able, willing, and seeking to work." We recommend a program of public service employment, providing, in effect, that the Government be an employer of last resort, providing work for the "hard-core unemployed" in useful community enterprises.

9. Technological change and productivity are primary sources of our unprecedented wealth, but many persons have not shared in that abundance. We recommend that economic security be guaranteed by a floor under family income. That floor should include both improvements in wage-related benefits and a broader system of income maintenance for those families unable to provide for themselves.

10. To facilitate adjustment to change as well as to improve the quality of life, adequate educational opportunity should be available to all. We recommend compensatory education for those from disadvantaged environments, improvements in the general quality of education, universal high school education and opportunity for 14 years of free public education, elimination of financial obstacles to higher education, lifetime opportunities for education, training, and retraining, and special attention to the handicaps of adults with deficient basic education.

11. Adjustment to change requires information concerning present and future job opportunities. We recommend the creation of a national computerized job-man matching system which would provide more adequate information on employment opportunities and available workers on a local, regional, and national scale. In addition to speeding job search, such service would provide better information for vocational choice and alert the public and policymakers to impending changes.

12. The public employment service is a key instrument in adjustment to technological and economic changes. But it is presently handicapped by administrative obstacles and inadequate resources. We recommend the now federally financed but State-administered employment services be made wholly Federal. This would bring them into harmony with modern labor market conditions. Then they must be provided with the resources, both in manpower and funds, necessary to fulfill their crucial role.

13. We recommend that present experimentation with relocation assistance to workers and their families stranded in declining areas be developed into a permanent program.

14. Displacement, technological and otherwise, has been particularly painful to those blocked from new opportunity by barriers of discrimination. The Commission wishes to add its voice to others demanding elimination of all social barriers to employment and advocating special programs to compensate for centuries of systematic denial.

15. Technological and economic changes have differential geographic impacts requiring concerted regional efforts to take advantage of opportunities and avoid dislocation. We recommend that each Federal Reserve bank provide the leadership for economic development activities in its region. The development program in each Federal Reserve District should include: (1) A regular program of economic analysis; (2) an advisory council for economic growth composed of representatives from each of the major interested groups within the district; (3) a capital bank to provide venture capital and long-term financing for new and growing companies; (4) regional technical insti-

tutes to serve as centers for disseminating scientific and technical knowledge relevant to the region's development; and (5) a Federal executive in each district to provide regional coordination of the various Federal programs related to economic development.

16. The responsibility of Government is to foster an environment of opportunity in which satisfactory adjustment to change can occur. But the adjustments themselves must occur primarily in the private employment relationship. The genius of the private adjustment process is the flexibility with which it accommodates to individual circumstances. Our report suggests areas for consideration by private and public employers, employees, and unions. We also recommend study of a reinsurance fund to protect pension rights and modifications of the investment tax credit to encourage employers to provide appropriate adjustment assistance. We also advocate a positive program by employers and unions to provide compensatory opportunities to the victims of past discrimination and stronger enforcement provisions in civil rights legislation relating to employment. Federal, State, and local governments are encouraged to conduct themselves as model employers in the development of new adjustment techniques.

17. Technology enlarges the capacities of man and extends his control over his environment. The benefits of increased productivity can and should be applied to combinations of higher living standards and increased leisure, improvements in the work environment, increased investment in meeting human and community needs, and assistance to less advantaged nations.

18. As examples of possible applications of new technologies to unmet human and community needs, we recommend improvements in health care, transportation, control of air and water pollution, and housing.

(1) To improve health care, we recommend: (a) Fuller access to diagnostic and patient care facilities by all groups in the population; (b) broader and bolder use of the community and other new health technologies; (c) increased spread and use of health statistics, information, and indexes; and (d) new programs for training health manpower.

(2) To aid the development of an efficient transportation system we recommend: Federal support of a system research program directed toward (a) the problems of particular multistate regions, (b) the determination of national transportation requirements, and (c) the evaluation of alternative programs.

(3) For air pollution control, we recommend: (a) Enlargement of research efforts to learn and understand the effects of various pollutants on living organisms; and (b) assignment of pollution costs to the sources of pollutants.

(4) To control water pollution, we recommend: The establishment of effective, amply empowered river basin authorities.

(5) To encourage improvement in housing technology, we recommend: (a) Federal stimulation of research; (b) use of federally supported public housing to provide initial markets for new housing technologies; (c) promulgation of a national model building code by making available Federal support and insurance of housing and other construction only in those communities which put their building codes in harmony with the national code; and (d) provision of adjustment assistance to any building crafts destroyed by technical change.

19. We also recommend (1) increased use of systems analysis in resolving social and environmental problems, (2) the use of Federal procurement as a stimulus to technological innovation through purchasing by performance criteria rather than product specification, (3) provision of Federal funds to universities and other organizations for the improvement of research techniques and their experimental application to urban problems, (4) the formation of university institutes integrated with the educational function which would serve as laboratories for urban problem analysis and resources for local communities wanting their advice and services, and (5) increased efforts to make available for non-government use results of Government performed or funded research.

20. Finally, we recommend: (1) Efforts by employers to "humanize" the work environment by (a) adapting work to human needs, (b) increasing the flexibility of the lifespan of work, and (c) eliminating the distinction in the mode of payment between hourly workers and salaried employees; (2) exploration of a system of social accounts to make possible assessment of the relative costs and benefits of alternative policy decisions; and (3) continuous study of national goals and evaluation of our national performance in relation to such goals.

21. Nelson, Richard R., Merton J. Peck, and Edward D. Kalachek. Technology, Economic Growth, and Public Policy. Washington, The Brookings Institution, 1967. 251 pp.

INTRODUCTION

Technological advance has generally mystified layman and economist alike. In the popular literature technological advance tends to be viewed as the result of the insight of a hero inventor, or as the automatic by-product of a great scientific discovery—in any case, an unpredictable and uncontrollable force. With few exceptions, until recently the economists's treatment of technological advance did little better in facilitating understanding of the subject. In most of the literature on economic growth, technological advance tended to float in the air as a factor which increased the productivity of capital and labor, its contribution being estimated sometimes by the residual in the growth rate after allowance for growth explained by other factors, sometimes by a time trend in productivity.[1]

In recent years economists and other social scientists have begun to deal more explicitly with technological change. Research has been undertaken on the relationship between productivity growth and research and development spending and other activities directed towards advancing technology. Other studies have examined the factors influencing the allocation of resources to advancing technology among the various sectors of the economy. Still other work has focused on the factors influencing the rate at which new technology is absorbed into the economy.[2] Part I of this book draws together much of this work, and attempts to further develop understanding of the relationship between technological advance and the economy.

Central to the analyses in Part I is an operational concept of technological knowledge. The discussion centers on the different kinds of pertinent knowledge, the various stages in its creation and application, the diverse inputs required in these stages, and the factors affecting the allocation of these inputs. Also examined is the interdependency between technological advance and other important factors in the process of economic growth, such as expansion and updating of capital stock, increases in educational attainment, and shifts in the allocation of resources from low to high productivity uses.

Part II deals with the ways the economy adjusts to technical change. It addresses the laymen's fears that the existing economic and social structures are not capable of adjusting to the consequences of technical change. In the past, technological change has destroyed the social and economic framework of traditional rural pursuits and small-scale craft production and brought job and income insecurity in its wake. Many people see this problem intensifying in the future, as a wave of automation inundates existing economic institutions.[3]

Professional economists generally take a more sanguine view of the future regarding job security. After three decades of revolutionary change in social policy, society seems on the verge of reconciling rapid technological advance with continuing high employment and a high degree of personal economic security. There remains, however, a serious reluctance to deal with other costs of technological advance and rapid economic growth, such as smog, water pollution, noise, congestion, and other hazards to health and safety which have become blights on the physical and psychological landscape. Indeed, society is still so lethargic in dealing with these problems that it often accepts them fatalistically as the "costs of progress."

Clearly, the net benefit that society reaps from technological progress depends in considerable degree on the costs of adjusting to change, and the costs of

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[1] Edward F. Denison, *The Sources of Economic Growth in the United States and the Alternatives Before Us* (New York: Committee for Economic Development, 1962), is an example of the first; Robert Solow, "Technical Progress, Capital Formation, and Economic Growth," *American Economic Review*, Vol. 52, No. 2 (May 1962), is an example of the second.

[2] See, for example, Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *American Economic Review*, Vol. 54 (December 1964); Edwin Mansfield, *Econometric Studies of Industrial Research and Technological Innovation* (New York: W. W. Norton & Co., 1967); Jacob Schmookler, *Invention and Economic Growth* (Cambridge: Harvard University Press, 1966), and Everett Rogers, *The Diffusion of Innovations* (New York: The Free Press of Glencoe, 1962).

[3] Perhaps the most striking example of the panic literature is Donald N. Michael, *Cybernation: The Silent Conquest* (Santa Barbara: Center for Study of Democratic Institutions, 1962). The report of the National Commission on Technology, Automation, and Economic Progress, *Technology and the American Economy*, Vol. 1 (Washington: Government Printing Office, 1966), takes a more balanced view.

inadequately adjusting. The extent to which society should foster technological advance therefore depends on the strength and weaknesses of existing adjustment mechanisms, a matter examined in Part II.

Part III is more directly oriented toward public policy concerning technical advance. Certainly this area is no longer ignored. Rther, there is considerable interest in federal policies to stimulate technical advance and channel it in more socially productive directions. Research and development (R&D) programs on supersonic civilian transport aircraft and inter-urban ground transport have been initiated. A program of support of textile research has begun, and a Presidential Commission has been formed to examine the patent system. Proposals have been made for a vast expansion of R&D for the nondefense public sector, and for support of civilian technology generally.[4] Since this volume was substantially completed, the Presidential Commission an Automation has reported, but its report became available after this manuscript was completed.[5]

Despite the ferment, and a considerable amount of action, policy making in this field has suffered from an inability to delineate the proper role of private and public financing and institutions, and from the lack of agreement on criteria for determining when government programs are justified. Part III of this book outlines a suitable framework for establishing such criteria. It suggests both a set of broad problem areas where new governmental programs might have positive results, and a general strategy for policy making in this area.

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22. Organization for Economic Cooperation and Development. The Conditions for Success in Technological Innovation. Paris, 1971. 169 pp.

Summary of Main Conclusions of the Report

Relevance to Science and Economic Policies

Technological innovation is defined here as the first application of science and technology in a new way, with commercial success. Fostering technological innovation is an important objective of national science policy, since considerable scientific and technological resources are devoted to innovative activities.

Furthermore, technological innovation makes a significant contribution to competitive strength in international markets, and the diffusion of innovation amongst its potential population of users to economic growth in all Member countries. The pressures for technological innovation and diffusion will continue to be strong as long as economic growth and international competitiveness are important policy objectives in the Member countries. The report's analysis is concentrated on technological innovation rather than on diffusion, mainly because of the relative lack of empirical information on the latter.

Some Characteristics of the Innovative System

Tho Essential Components

Successful technological innovation always requires the existence of three factors: scientific and technological capability, market demand, and an agent which transforms this capability into goods and services which satisfy the demand. In the OECD countries, this agent is the industrial firm, the pressures and incentives being competition and profit, mainly through product innovations but also through cost-reducing process innovations.

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[4] For an example, see *Report of the Committee on Economic Impact of Defense and Disarmament*, July 1965 (Washington: Government Printing Office, 1965), particularly pp. 51–55; U.S. Department of Commerce, U.S. National Bureau of Standards, "Improving the National Climate for Invention and Innovation" (Washington: The Bureau, mimeo, 1965); and Council of Economic Advisers, *Economic Report of the President Together with the Annual Report of the Council of Economic Advisers* (Washington: Government Printing Office, 1962), pp. 123–27. See also the report of the National Commission on Technology, Automation, aand Economic Progress, *op. cit.*, Chaps. 6 and 7.

[5] The report of the Automation Commission concerns many issues discussed in this book. At various places reference to the report is made in footnotes. While the report material would not alter the authors' approaches or conclusions, had it been available earlier, it would have been given more extensive reference in the text itself. The varioius monographs sponsored by the Automation Commission were not available at the time of printing.

"Technology-Push" vcrusus "Demand Pull"

According to the results of four empirical studies, between two-thirds and three-quarters of innovations are initially stimulated by a clear definition of market needs. However, the remaining technology-stimulated innovations include relatively more innovations of a radical nature, which provide the basis for a larger number of more minor innovations, oriented towards the satisfaction of well defined market needs.

Differences Amongst Industries

In spite of the relative concentration of R and D activities in a few industrial sectors, many other sectors of the economy benefit from science and technology, through being suppliers or customers of the research-intensive industries. According to a U.S. study, these research-intensive industries employ relatively large numbers of qualified scientists and engineers, not only in R and D, but also in production, marketing and general management. They also have relatively high proportions of total employment outside production and high levels of concentration; but they are not particularly capital intensive, nor are they relatively big consumers of raw materials.

Three factors have been put forward to explain the varying research-intensity of industrial sectors, namely, variations in technological opportunity, quality of management, and market opportunities. But there is no empirical evidence on the relative importance of these factors which may, in any case, be interdependent. Technological advances in materials, automation and informatics offer considerable opportunities for application in sectors which are not at present research-intensive. Managements in these sectors may themselves exploit these opportunities, which will otherwise be seized by the research-intensive industries themselves.

Industrial Structures

The empirical evidence suggests that both large and small firms play essential roles in the process of technological innovation, and that these roles are complementary, interdependent and ever changing.

They are complementary in that larger firms have tended to contribute most to innovation in areas requiring large scale R and D, production or marketing resources, whilst smaller firms have tended to concentrate on the supply of specialised but sophisticated components and equipment—often with large firms as customers. In addition, however, small firms have often made very major innovations, either because large firms have not had effective methods of evaluating and implementing radical proposals, or because major innovations often involve great uncertainties so that even the best managed of large firms may let important opportunities slip through their fingers.

The roles of large and small firms are interdependent because small firms are often started by scientists and engineers with previous experience in large firms. Sometimes the establishment of these "spinoff" firms has been actively encouraged by large firms. Sometimes it has happened by default. Small science-based firms flourished earlier in the United States than in other Member countries, partly because of a more favourable market and financial environment and of a greater degree of personal mobility.

Finally, the roles of large and small firms are ever changing. As a technology matures in one sector, scale factors tend to become more important. But, as one technology matures, another enters a period of growth, thereby opening other and new opportunities for smaller firms. Hence the need for mobility and flexibility of innovative resources—and particularly skilled manpower and capital—in order to respond to the ever changing opportunities and requirements of technological innovation.

The Size of National Markets

Studies in the USA have suggested that the size and sophistication of the U.S. market has been a key factor in the innovative strength of U.S. industry. However, this explanation does not appear to hold for all Member countries. There are countries with very small national markets, but also with the technological and entrepreneurial capabilities enabling them to respond to demands for innovation on world markets. However, overcoming barriers to national markets has its costs, and can reduce the rewards and returns to successful innovators. In particular, the penetration of foreign government markets appears to have been particularly difficult, and to have had important effects on patterns of innovative performance in certain sectors.

The Management of Innovation

Technological innovation poses many difficult and sometimes novel problems to management, given the uncertainties and long time horizons involved, and given the need for communications across disciplinary and functional boundaries. Hence the need for "entrepreneurial" organisational forms, with flexible definitions of responsibilities and large possibilities for lateral communication, capable of evaluating and responding to new—and often unforeseen—technical and market circumstances. Hence also the need for top management's commitment to taking risks.

Study and teaching specifically related to the process of innovation may be particularly valuable—for both research workers and managers—given the difficulties of applying successfully many of the conventional management techniques. Furthermore, the increasingly worldwide competitive and market environment within which technological innovation takes place requires a careful definition of the role of R and R in achieving company objectives: in particular, the definition of the appropriate mix of "offensive", "defensive" and "absorptive" R and D strategies.

The Role of Fundamental Research

Fundamental research undertaken mainly in the universities plays an essential role in the process of technological innovation. It enlarges the pool of knowledge from which innovative activities draw, and is an essential input into the training of manpower for applied research and development activities.

The experience of eleven Member countries suggests that strong links exist between national potentials in fundamental research and national strengths in technological innovation. Although the results of the world's fundamental research are, in narrow economic terms, a "free good", the effective absorption of the results of foreign fundamental research requires an indigenous fundamental research effort—certainly in the universities and, at higher levels of technological development, also in industry.

Furthermore, the transfer of knowledge between science and technology is mainly "person-embodied": in other words, it takes place through people talking to one another, or through people moving from one institution to another. Hence the importance of integrating the results of fundamental research rapidly into the teaching process, of university staff consulting with industry, and of university-based refresher courses for industrialists.

Conversely, strength in technological innovation also affects the quality of fundamental research. It leads to industrial growth and thereby induces greater demands for university education and research, either through direct, industrial financing of certain university activities, or through the sensitivity of governmental educational policy to industrial requirements.

THE ROLE OF GOVERNMENT

Government is not the primary agent for the generation and application of scientific and technological knowledge. This role belongs to the universities and industry. But experience has shown that government policy, when oriented towards well-defined objectives, can have an important influence on the resources, incentives and barriers related to the innovative process.

Objectives

However, no general policy prescriptions can be made which will be applicable in all countries, because countries differ in resources, environment and objectives, and not enough is known about the impact of various components of government policy. Nonetheless, successful, national innovative systems appear to be bound up with strong fundamental research coupled with a capability in industrial R and D, orientation towards world markets, and flexible structures and methods which ensure that multiple channels are kept open for the creation, transfer and application of technology.

The Deployment of R and D Resources

Even where variations in absolute size are taken into account, there are big differences amongst Member countries in the level of resources devoted to R and D performed in industry. For R and D financed by industry, the differences are smaller, although still important.

Government performed R and D has decreased as a proportion of total R and D in countries where it has been high. Although total levels of R and D funding, and the objectives of government-financed R and D, have often evolved rapidly, patterns of performance of R and D changed only slowly.

Many governments are taking measures to couple government performed R and D more closely to industrial needs. At the same time, government measures to promote industrial R and D have been successful when R and D has been the main bottleneck in the innovative process, but not otherwise.

National Technological Specialisation

The increasingly open and interdependent OECD region requires national specialisation within areas of advancing technology. The existing patterns of national specialisation reflect government objectives and access to raw materials, as well as the sanctions of commercial success in world markets. Government can reinforce existing patterns of specialisation through rewarding successful, innovating firms, and can help create new patterns in the longer term by building up new strong points in scientific and technological capabilities.

Large-Scale Technological Programmes

Governments are often involved in financing large-scale scientific and technological programmes which have a strong influence on the pace and direction of scientific and technological advance, as well as on the use of resources. These programmes have had important effects on technological innovation in specific sectors. But some countries have a strong national performance in technological innovation without such large-scale programmes. The extent to which governments will finance large-scale programmes related to technological innovation will depend on their attitudes to, and resources available for, costly, high risk and high return projects, as well as the degree of internationalisation of participation in large-scale programmes in future.

Creating a Climate Favourable to Technological Innovation

When considering more general policies for the creation of a climate favourable to technological innovation, three key characteristics of the innovative process must be borne in mind. First, the outcome of innovative activities is uncertain, so that risk taking must be rewarded, and individuals and institutions must have the ability to adapt to new and unforeseen situations. Second, innovation often implies uncomfortable changes, so that pressures must exist for change, and its social costs reduced as far as possible. Third, the transfer of technological knowledge is mainly "person-embodied", so that mobility and person-to-person contacts must be encouraged, both within and amongst institutions at the various stages of the innovative process.

These requirements suggest a number of objectives for government policy, such as:

Ensuring industrial competition, as the main pressure for technological innovation;

Ensuring equitable rewards for innovations, through the tax and patent systems;

Ensuring that regulations, codes and standards take account of both the social costs and benefits of the innovative process, as well as the flexibility and pluralism required for successful innovation;

Having active regional and manpower policies to deal with the changes in industrial and skill patterns brought about by technological change;

Using government procurement to upgrade the technical level of industry, and to couple technology more effectively to collective, social needs;

Encouraging the mobility of scientists and engineers, especially in and out of government laboratories;

Identifying policy measures to encourage science-based entrepreneurship;

Ensuring continued trade and capital liberalisation, thereby heightening the pressures and incentives for technological innovation in all Member countries, and maintaining the rapid, international spread of the benefits of new technology.

23. Organization for Economic Cooperation and Development. Gaps in Technology. General Report. Paris, 1968. 41 pp.

IV. Policy Implications

1. Definition of the Policy Problem and Areas of Possible Action

112. The differences in levels of scientific and technological capability and in innovation in industry that have been brought to light are not entirely new, but represent trends of long standing. What, then, are the factors that account for the present concerns? The evidence of the OECD studies suggests the following:

(*i*) Products of industrial sectors which require much R and D and innovation are growing in number and in importance. Although their weight in the total output of the Member countries is still relatively small, as compared, for example, with agriculture and construction, their role in the total industrial economy of advanced countries is generally conceded to be of growing importance. This is partly because it is believed their impact on more traditional industrial sectors may be important, and partly because of their growing importance in world trade.

(*ii*) Together with the above trend, there is some feeling that in certain science-intensive industries the point may be reached after which it will become increasingly difficult for new firms to enter the market successfully.

(*iii*) Although technology is being effectively transferred among Member countries, the relative importance of foreign investment as a vehicle for transfer appears to be increasing. This fact has raised the issue of the effect of location of industrial decision-making on national economic, employment and research policy. This matter is linked with the important role now played by international companies which operate on a world-wide basis, and in some cases have a strong leadership position in the total market.

113. Thus, the growing importance of science-intensive industries, the increasing "price of entry" to the market, and the growing role of direct investment and international companies in the process of technological transfer appear to be the new factors which explain the *political* importance of the issues which this report is concerned.

114. The findings of the OECD study would suggest that three main lines of action are required. *First of all*, individual countries will need to take measures to enable their industries to strengthen their performance in original innovation, and their abilities to exploit these innovations in the market. This can only be achieved by deliberate efforts on the part of the countries themselves. *Secondly*, groups of Member countries, including the European members, will need to develop more effective forms of cooperation in order to overcome the existing fragmentation of markets, industries and technological efforts. Success in this direction is necessary if cooperation and exchange between the United States and other Member countries is to be effective. *Thirdly*, co-operation between all the Member countries will be needed to avoid the development of obstacles to technological exchanges, thereby increasing the benefits to all. Each of these three aspects of policy will now be discussed.

2. Policies at the National Level to Strengthen Performance in Innovation

115. There is a wide range of measures at national level which would contribute to building up national and scientific and technological capabilities and success in original innovation. These measures would imply a *new stage in science and technological policy in coming years*, including close integration with economic, industrial and commercial policies. The principal objectives of this new stage would be:

(*i*) to relate government science policy more explicitly to clearly-defined economic, social, defence and other objectives, in order to provide clearer orientation of effort, leading to better utilization of and more economic output from scientific and technological resources;

(*ii*) to define the possible contribution of science and technology to a wider range of government objectives;

(*iii*) to strengthen communication and co-operation among industry, the universities and government agencies, in order to overcome the "isolation" of science and technology from those who may apply their results;

(*iv*) to consult industry much more comprehensively in the formulation and execution of policy, in particular in Europe, in order to overcome the weaknesses in the innovation process in some Member countries as revealed by the present study.

116. There is no unique prescription for policies in these directions. Economic, industrial and social policies are clearly just as much involved as, and interrelated with, those in science and technology. Some of the following would, however, provide the basis for a new partnership between industry and government and thereby help to strengthen Member countries' performance in original technological innovation.

3. International Co-Operation in Science and Technology Between Member Countries and Groups of Member Countries

135. Although the actions reviewed above are important, more needs to be done if the pace of technological innovation is to be accelerated. For this to be achieved, other Member countries and groups of Member countries, for example, in Europe, are considering programmes for science and technology which, even if not of the same size as the space programme of the United States, nevertheless have the same power to catch the imagination of the industrial, scientific and educational communities, and the means to overcome institutional barriers and traditional attitudes. If the United States' experience is a pointer it seems beyond doubt that the political will to undertake such programmes will depend on their being the *instruments* for attaining important and stimulating objectives. Moreover, since programmes in advanced areas of technology, such as space, aviation and nuclear energy, and an increasing number of areas of civil technology, are in many cases beyond the resources of individual countries, they will depend on the identification of objectives which can be agreed between groups of countries.

THE REQUIREMENTS FOR EFFECTIVE INTERNATIONAL CO-OPERATION

140. Whilst the need for major programmes of cooperation in science and technology related to social and economic objectives is clear, there are a number of fundamental difficulties which call for examination:

the need for more clarity or agreement concerning the objectives for which the projects are undertaken and the policies for achieving them;

lack of means for the systematic examination of the alternatives for achieving a desired policy objective, or the alternative methods of managing a given project or programme;

the seemingly inevitable competition between national and international projects;

the difficulties of reconciling the need for efficiency and managing such projects, with the desire for each participating country to achieve a fair return in every specific area of cooperation:

intergovernmental co-operation in applied R and D projects must often go hand in hand with inter-country co-operation in industry and in government procurement.

141. Quite apart from the above difficulties, there remains the problem of choosing objectively the most appropriate framework for international co-operation, and of working out effective and realistic arrangements for political and managerial control. Whilst there have been some past successes, there has also been a sufficient number of difficulties to make it clear that, although it is urgently necessary to give a new impulse to international scientific and technological co-operation, it is equally important to establish an effective mechanism or forum for evaluating possible projects, so that governments may have a clear picture of the objectives to be served, and alternative methods for achieving these objectives.

142. In addition to this need for *evaluation*, decisions should be related to future needs, and emerging technological opportunities. Otherwise, the priorities for effort will run the risk of not reflecting the real options, which must of necessity be formulated having regard to possible technological and market trends.

143. These considerations suggest that the efforts of individual countries to evaluate possibilities and develop an effective role in international co-operation in science and technology could be significantly assisted by arrangements to carry out the following functions:

(*i*) assessment of social and economic objectives in Member countries, in relation to which there are potential contributions from technology which call for international co-operation;

(*ii*) evaluation of proposed international projects in relation to these objectives, including the formulation of criteria which would assist Member countries in such evaluations;

(*iii*) examination and evaluation of management requirements for large-scale co-operative programmes.

4. Policies To Increase the Benefits of International Technological Exchanges

152. While scientific and technological projects undertaken in common provide one example of the way in which the benefits of technological advance can be shared, a great deal of technological flows between countries takes place through the processes of trade in goods, capital movements, purchases of technological know-how and the migration of professional manpower. It is important that, where necessary, action should be taken to facilitate these flows.

153. The structure of trade in manufactured goods does in itself seem to reflect a certain pattern of relationships in terms of technology. The United States seem to lead in the production and exportation of new products. Western European countries, once in the position occupied today by the United States, retain a capacity for innovating new products in some sectors, but in many cases they are brilliant followers based on the early adoption of innovations made in the United States and elsewhere. Japan, formerly competing in products based on "traditional" technology, has moved up to a position similar to that of some European countries, and in some key sectors is an original innovator.

154. Thus, trade in goods has enabled countries to acquire technologies as a result of liberal trading policies. However, the above pattern of relationships in technology will continue to evolve if Member countries succeed in developing their innovative capabilities.

155. In this connection the reduction of *non-tariff barriers to trade* would undoubtedly be beneficial to flows of technology. Industry is sometimes hampered by the need to diversify its products for export in order to fit in with varying standards, certification procedures, safety requirements, etc.; by varied patent procedures in different countries, and by regulations and restrictions in the field of government procurement. There is in consequence a definite need to harmonize standards, to consider patent legislation on an international basis, and to liberalize and harmonize government procurement.

156. In addition, countries are bound to ask themselves how they can to some extent produce their own advanced technological products and thereby benefit from the rapidly growing markets for such products. There are a number of ways in which they may develop their production facilities, either through licenses, foreign investment, or by generating the technology domestically.

157. As far as licensing is concerned, the system of patent monopoly has contributed much toward avoiding wasteful duplication of research and development, ensuring the effective building-up of scientific and technical knowledge, and acting as an incentive to invention and especially to innovation. However, some patents are now so basic to the development of important sectors of industry, and the pace of technological change has become so fast, that fears have been expressed about the possibility that access to some important inventions and the related licenses may be restricted. It may be desirable to give some attention to aspects of this question.

158. Foreign investment may be considered an alternative to licensing, depending on the particular circumstances of competition between firms in different countries, and on national policies. In Europe, for example, foreign investment, principally from the United States, has undoubtedly contributed to the effective transfer of technologies. However, foreign investment on a large scale raises the question of control of decision-making over important sectors of national economies, and calls for developments in national and company policy whereby the contribution to the national economy can be most effective, while allowing for a fair return for the investor. Foreign subsidiaries and joint ventures also contribute to the level of technological development in the host country, especially if the strategy of the firms concerned is to conduct R and D in their subsidiaries and joint ventures and diffuse the technology in question in the recipient economy.

159. An important additional process in the transfer of technology is the mobility of scientific and technical manpower. Whereas the provision of education is mainly a national concern, the labour market for qualified persons emerging from any educational system is becoming increasingly *international*. If a country produces more persons with certain qualifications than its economy can absorb, these persons may be expected to seek lucrative employment in countries with a higher standard of living, and the country losing manpower will experience a "brain drain". A country producing fewer qualified people than required by the private and public sectors of the economy will tend to attract them.

160. Licensing, foreign investment and the "brain-drain", should be seen in the broad context of technological development and exchange under modern conditions. The efficient exploitation of advanced technologies calls for both technological resources beyond national boundaries and access to markets that are international in scope. This, added to the mobility of the factors of production (essentially knowledge, qualified manpower and capital), leads to a new emphasis in international exchange. Flows of manpower, investment and knowledge are undoubtedly beneficial to all countries but in this new situation some countries are experiencing problems which affect the development of their own technological capabilities.

161. It is also important to bear in mind the special plight of the under-developed countries. For, whereas the evidence suggests that technology has been effectively transferred between the Member countries, the same is not true for the under-developed countries. The absence of scientific and technological capability in these countries may be an important factor in limiting the transfer of technology to them, and the aid to them in developing indigenous R and D capability may be an increasingly important task for the Member countries.

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24. Organization for Economic Cooperation and Development. Policies for the Stimulation of Industrial Innovation Analytical Report, v. 1. Paris, 1978. 167 pp.

PREFACE

(By Professor C. Freeman) [1]

I. THE IMPORTANCE OF POLICIES TO STIMULATE INNOVATION

The introduction to the Report argues that government policies for innovation are likely to remain an extremely important aspect of public policy. Disillusion with some of the unwelcome side effects of technical change will not diminish the need for innovations, rather the opposite. Similarly, shortages of primary commodities or of other resources are acting as an additional impetus to innovation. It is difficult to dispute the conclusion that "the long-established interest of Member governments in the innovation process is today becoming even more marked". At the same time as new programmes and institutions have been started in most Member countries, older organizations and measures have been modified or transformed to serve new purposes. Old public scientific laboratories are increasingly "mission-oriented" and the older "big science" programmes are adapted to cope with the energy crisis.

II. PROBLEMS OF THEORETICAL GENERALISATION IN INNOVATION STUDIES

The Report shows that most national authorities (with the exception of the United States) attempt little systematic evaluation of PSI. It has also demonstrated the shortcomings of some of the traditional approaches which influence decision-making. But a comparative survey could go further. Even though constructive criticism of some national policies may occassionally be unwelcome to this or that national authority, the Member governments of OECD are sufficiently mature in their approach to comparative research to recognise that this is one of the main benefits of an international organization. Economic policies, educational policies and environmental policies of Member countries have all benefitted from this type of friendly but critical international evaluation and comparison within the framework of OECD research and discussion. Such evaluation

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[1] Director of the Science Policy Research Unit University of Sussex (United Kingdom). In this preface, written at the request of the *ad hoc* Group, Professor Freeman expresses its personal views on PSI and the problems which are raised by their study.

and discussion depends of course on some commonly agreed theoretical framework. But such a consensual framework has in fact been emerging during the last ten years, partly as a result of the OECD's own efforts. A few examples may serve to illustrate the type of thing which might be attempted: one obvious example is the question of subsidies to industrial R&D. There is evidence in the survey that these are playing an increasingly important part in the PSI of many Member countries, even in some which have traditionally been unsympathetic to the conception of public subsidies to private firms. There is an abundant economics literature on the whole question of subsidies to particular industries or firms. There is also an increasing volume of evidence on the relevance of this theory to the special case of industrial innovation.

Broadly speaking, almost all schools of economic theory have established a strong case against subsidies to particular firms and industries, arguing that in the long run they are likely to lead to a mis-allocation of resources and to a diminution of welfare. There is also strong evidence from the theory of government and public administration that ad hoc subsidies to individual firms may prove in the long run difficult to administer fairly and efficiently. Finally, there is evidence from the specific field of innovation studies that subsidies to R&D may not even be the most effective form of subsidizing innovations. R&D performance is by no means identical with innovation performance and it is the latter with which PSI are primarily concerned.

Case studies of industrial innovations in many OECD countries, together with some more systematic comparative studies, have now established a fairly well-organised body of knowledge on the circumstances surrounding successful innovative performance. Simply to spend more money on R&D cannot in itself ensure success, and may indeed make failure more likely. In most industrialised countries private firms are ready and able to finance those innovations which they believe will be profitable. There is a real danger that when subsidies are requested they will be for the less satisfactory projects. Moreover, a whole series of innovation studies have demonstrated that the most common causes of failure are not those associated with lack of finance for development, but those related to a poor understanding of the market and failure to relate technical development to the needs of potential users. A very common pattern of failure is the pursuit of a technologically interesting idea without sufficient regard to its potential profitability or consumer demand. The availability of generous R&D subsidies seems far more likely to reinforce this pattern of behavior than to weaken it.

All of this would suggest that more efficient and socially desirable forms of PSI might emerge from procurement policies rather than from R&D subsidy policies, or at least from a well conceived combination of the two. One of the few empirical studies which made some comparisons between these alternatives came to the firm conclusion that procurement was far more effective than subsidy in one industry where both were used on a large scale. This was the U.S. semi-conductor industry which has been the subject of detailed investigation by Golding and by Tilton. Golding concluded not only that procurement policies had been far more effective than subsidies in the United States, but also that the subsidy policies used in several European countries had been largely ineffective.

Yet there is scarcely any mention of the role of the market or procurement policies in the national replies to the OECD survey. This is clearly a case where there is some divergence between the findings of research and the views of some policy-makers on appropriate and useful PSI. Some further research by the OECD on this issue could conceivably lead to an important change of emphasis in policy, just as the findings of research led to major changes in international trade and employment policies in the past.

All of this does not mean that there may not sometimes be a strong case for R&D subsidies in particular countries, in particular industries. Economic theory has for a long time indicated that tariffs and other forms of protection, like subsidies, lead to inefficiency and loss of welfare. National and international policies have been strongly influenced by this theory and this is reflected in the steady pressure of GATT, the OECD, the EEC and other international organisations to reduce the barriers to trade by agreement. But economic theory has generally accepted that there are important exceptions which may justify national protective measures, at least temporarily, and these exceptions are reflected in the relevant international agreements. For example, the "infant industry" argument is an important consideration, which by extension may be applied in the early stages of industrialisation to the whole of manufacturing industry in developing countries. Again, another important exception to the general rule is in the whole area of "strategic industries". The applications of this are often highly controversial, particularly for example in relation to agricultural products, such as sugar or wheat, and industrial products with both military and civil applications such as computers or aircraft. No one could possibly argue that international trade theory provides easy answers to all these complex and difficult questions, but it does at least provide a framework within which they may be discussed. Similarly, in the case of subsidies to R & D: it should now be possible to discuss these within a general theoretical framework rather than on a purely pragmatic ad hoc basis. This does not mean that such a framework should be based on the increasing importance of social criteria. But where subsidies are used the onus should be on policy-makers to indicate the specific justification for this type of measure.

Similar considerations apply to the discussion of the role of government laboratories, rewards to inventors, tax incentives, public procurement and several other PSI. Much work in the social sciences on regional policies, on public finance, and on communication theory is relevant here, as well as the specific work on industrial innovation.

Consider for example the role of government laboratories. The response of the member countries on this question was extremely uneven, but all of them have important public laboratories and are concerned about their future role. Here too the findings of theoretical and applied economics have extremely important implications for government policy. Several empirical studies (for example TRACES, Gibbons and Johnston) have demonstrated the importance of information inputs from public and university laboratories for technical innovation by industry. Nelson and his colleagues have demonstrated an extremely strong case for government endowment of long-term basic research, which has not been rejected or refuted by any school of economic theory. Nelson has further argued that there will be a chronic tendency for industry to under-invest in long-term research. Whilst Hirschliefer has argued that firms may be more capable of profitable appropriation of the results of their own basic research than Nelson allows for, he has not refuted his general case. There is a clearly mutual advantage to be derived from industry concentrating on experimental development and commercialization, with government financing more fundamental and more long-term research. As Pavitt has pointed out, government finance of public laboratories and universities complements industry's own R & D programmes and this is more valuable than to supplement them by subsidising development. Nelson, Peck and Kalachek argued ten years ago that the main concern of public laboratories should be "fundamental technology" and not development.

It seems that on the one hand there is a danger of pushing government laboratories into short-term development in an effort to make them more "relevant", and on the other hand there is a danger of government laboratories becoming the cinderella of PSI, whilst subsidies to firms are increased, and this applies even more to Research Associations. Yet these changes in the emphasis of government policies are due less to any serious comparative evaluation of PSI than to a vague feeling that the industrial firm is where the action is and that it is here that effort needs to be concentrated. The apparently poor showing of some public laboratories and RAs may well be due to problems of interface with industry and technology transfer than to a basic mis-allocation of government expenditures. Evidently, here too there is important scope for OECD research on the evaluation of RAs and public laboratories, concentrating in particular on programme selection and transfer mechanisms.

From the Report and from other evidence it is clear that governments since the war have given a much higher priority to special measures related to "high technology" industries than to the RAs. The RAs are concerned much more with industries of relatively low research-intensity and often composed of smaller firms. Yet insofar as industrial efficiency is the main concern of government PSI there would be a strong case for concentrating more attention on a wide range of industries, rather than the preoccupation with glamorous high technologies. Here again there is a clear need for OECD research. In the 1950s the OECD did a pioneering comparative study of the RAs, but since then it has almost entirely neglected this extremely important area of government involvement with technical change in industry. Yet a great many new developments have taken place in the RAs and there is much that countries could learn from each other by a really good comparative study.

To sum up these points, it is clear from the Report that although governments have shown increasing interest in PSI, and have been willing to introduce many new measures, they have devoted realtively little attention to studying the relative efficacy of PSI or their impact. Comparative research, using the results of much recent empirical work could throw a great deal of light on this question, and possibly prevent some mis-allocation of resources.

Finally, although the Report argues very convincingly in Chapter I that "social innovations" in such areas as housing, health and transport are of growing importance for PSI, this theme subsequently receives little further mention or discussion. Yet this is surely a topic which merits a great deal of further research and which is relvant to almost all the PSI which are discussed, whether this is undertaken within the framework of a social cost/benefit type of analysis, or this approach is discarded because of its inherent limitations and a wider approach is adopted.

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25. **Pavitt, K., and W. Walker. Government Policies Towards Industrial Innovation: A Review.** Research Policy, vol. 5, January 1976 : 11–97.

SUMMARY

Existing economic theories show that continuing innovation, diffusion, and technical and managerial improvement are necessary for economic growth and international competitiveness in the industrially advanced countries. But knowledge of why, where and how governments should intervene in the processes of industrial innovation stems more from trial and error than from systematic empirical information of the nature and extent of the handrances to economically and socially desirable innovations, and of the effectiveness of alternative government policies to remove them. Nonetheless, past empirical studies do offer some clues.

Differences amongst industrial sectors.—The sources of new technology vary widely amongst industrial sectors: in the costs of innovation, in the relative importance of outside suppliers of equipment and materials, of large and small firms, and of full-time R. & D. departments as compared to part-time innovative activities. Similarly, the conditions for successful innovation vary amongst sectors. Thus, government policies designed to influence innovation are likely to act with different intensitfes in different industries.

The management of innovation.—Nonetheless, there are some features common to innovation in different industries. Considerable costs beyond R. & D. are often necessary before the innovations reach commercial use. And the following managerial characteristics are in general associated with successful innovation: a deliberate policy of seeking innovations; close and careful attention to customer requirements; good personal communications both within the firm and with outside sources of relevant knowledge; a style of management that is 'organic' and 'participatory' rather than 'hierarchical' and 'authoritarian'; strong project leadership; and a strong engineering capability.

R. & D. managers are still unable to predict the outcome of R. & D. projects to a useful degree of accuracy and, in the literature on methods of project selection, very little attention is paid to market uncertainties. Furthermore, a greater use of conventional investment appraisal criteria in deciding on R. & D. projects may re-inforce the already observed tendency in industry towards short-term, low-risk projects, to the neglect of longer-term, high-risk projects.

Governments should therefore examine whether the benefits of policies towards education and management advisory services for innovation might outweigh their costs. They may also have a significant role to play in financing longer-term research that is basic to the development of industrial technology.

The nature of market and production demands.—The direction of industrial innovation is often very sensitive to market and production demands (sect. 3). This fact, together with the high degree of market uncertainty facing innovating firms, suggests that governments can potentially influence both the pace and the direction of industrial innovation through their influence on the scale of industrial, consumer and public service demands. However, this potential influence will become real only if users of innovations are able to specify the innovations that they need, or to evaluate those that they get. This is generally the case for industrial demand, but not in consumer and public service markets, where

fashion, insensitivity to users' needs and lack of technical competence often prevail. Government-funded technological institutes and laboratories are ideally placed to provide such technical competence.

Economic incentives and rewards for innovation.—A whole range of economic factors are said to influence the resources, the incentives and the rewards for innovation: for example, the degree of monopoly or the degree of competition, the patent system, the level of profits, the level of taxation, and the level of demand. The empirical evidence on the effects of most of these factors on industrial innovation is either inconclusive or non-existent. However, in the United States a close relationship has been observed between growth of industry sales and growth of industry-financed R. & D. activities. The rate of growth of demand is also one of the key factors influencing the rate of diffusion of innovations amongst their potential population of users.

The government-financed scientific and technological infrastructure.—Scientific and technological knowledge from outside of innovating firms is often crucial to the completion of successful innovations, and three UK studies show that a significant proportion of this outside knowledge comes from government-financed technological institutes and laboratories, and from the universities. If the same is true in other countries, it should be an essential feature of any government policy towards industrial innovation to know how effectively government-funded laboratories and universities provide supportive knowledge to industry, and how government laboratories should be organised and financed.

Direct government-financing of innovative activities in industry.—Governments specifically finance R. & D. activities in industrial firms, although these expenditures are less than those for general industrial development. These R. & D. activities in industry are relatively more important in France and UK, than in F.R. Germany and the Netherlands.

In the four countries, more than 70 percent of all civilian government R. & D. activities related to industry are spent on aircraft, space, nuclear energy and electronics. In all these high technologies, governments attempted in the 1960's to implement 'policies for innovation', involving government procurement, industrial mergers and attempts at European co-operation, in addition to the financing of R. & D. Government expenditures on civilian R. & D. related to other industrial sectors are very much smaller in all four countries.

Where should governments intervene?—A number of attempts have been made to develop a formal framework of criteria to assist governments in deciding where they should intervene in industrial innovation. They all run into the following difficulties: dealing with multiple policy objectives; assessing national costs and benefits; comparing with alternative policies, choosing appropriate policy instruments.

How should governments intervene?—Very little information is available on the effectiveness of various policy instruments that have been used by governments in order to promote innovation in industry. Although it is often possible to measure the inputs into such policies, the measurement of their outputs (or results) is more difficult. Nonetheless, detailed studies would enable some such measurements to be made, and internationally comparable studies would increase the range of experiences and the number of cases that could be examined.

Why should governments intervene?—A full appreciation of the nature and scale of hindrances to industrial innovation, on which governments should act to remove, requires direct information on what innovations are (or are not) being introduced by industry, and why they are (or are not) being introduced. This information can best be obtained from analyses of the behaviour of industrial firms. They would differ from most existing innovation studies that concentrate on asking how firms must behave in order to make successful innovation, by asking what innovations are attempted), and why firms are stimulated to attempt them.

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26. Rogers, Everett M. Diffusion of Innovations. New York, Free Press, 1962, 380 pages.

GENERALIZATIONS

Throughout the book, a number of generalizations have been presented to synthesize the major findings. A total listing of these generalizations provides a skeleton summary of the major conclusions of what is now known about the diffusion of innovations.

1. Innovativeness of individuals is related to a modern rather than a traditional orientation.
2. An individual's innovativeness varies directly with the norms of his social system on innovativeness.
3. Relatively later adopters are more likely to discontinue innovations than are earlier adopters.
4. Impersonal information sources are most important at the awareness stage, and personal sources are most important at the evaluation stage in the adoption process.
5. Cosmopolite information sources are most important at the awareness stage, and localite information sources are most important at the evaluation stage.
6. There is little evidence that lack of knowledge about innovations actually delays their adoption.
7. Awareness occurs at a more rapid rate than does adoption.
8. The first individuals to adopt innovations require a shorter adoption period than do relatively later adopters.
9. The awareness-to-trial period is longer than the trial-to-adoption period.
10. The awareness-to-trial period is shorter for relatively earlier adopters than for later adopters.
11. The trial-to-adoption period is longer for relatively earlier adopters than for later adopters.
12. Earlier adopters try innovations on a smaller scale than later adopters.
13. A crisis emphasizes the relative advantage of an innovation and affects its rate of adoption.
14. The relative advantage of a new idea, as perceived by members of a social system, affects its rate of adoption.
15. The compatibility of a new idea, as perceived by members of a social system, affects its rate of adoption.
16. The complexity of an innovation, as perceived by members of a social system, affects its rate of adoption.
17. The divisibility of an innovation, as perceived by members of a social system, affects its rate of adoption.
18. Relatively earlier adopters may perceive divisibility as more important than later adopters.
19. The communicability of an innovation, as perceived by members of a social system, affects its rate of adoption.
20. Adopter distributions follow a bell-shaped curve over time and approach normality.
21. Earlier adopters are younger in age than later adopters.
22. Earlier adopters have higher social status than later adopters.
23. Earlier adopters have a more favorable financial position than later adopters.
24. Earlier adopters have more specialized operations than later adopters.
25. Earlier adopters have a type of mental ability different from that of later adopters.
26. Impersonal sources of information are more important than personal sources for relatively earlier adopters of innovations than for later adopters.
27. Cosmopolite sources of information are more important than localite sources for relatively earlier adopters of innovations than for later adopters.
28. Earlier adopters utilize information sources that are in closer contact with the origin of new ideas than later adopters.
29. Earlier adopters utilize a greater number of different information sources than do later adopters.
30. Earlier adopters are more cosmopolite than later adopters.
31. Earlier adopters have more opinion leadership than later adopters.
32. There is considerable shifting of individuals in a social system from one category to another over time.
33. Laggards are most likely to drop out of the social system.
34. Innovators are perceived as deviants by other members of their social system.
35. Innovators perceive themselves as deviant from the norms of their social system.
36. Personal influence from peers is most important at the evaluation stage in the adoption process and less important at other stages.
37. Personal influence from peers is more important for relatively later adopters than for earlier adopters.

38. Personal influence from peers is more important in uncertain situations than in clear-cut situations.
39. Opinion leaders conform more closely to social system norms than the average member.
40. There is little overlapping among the different types of opinion leaders.
41. Opinion leaders use more impersonal, technically accurate, and cosmopolite sources of information than do their followers.
42. Opinion leaders are more cosmopolite than their followers.
43. Opinion leaders have more social participation than their followers.
44. Opinion leaders have higher social status than their followers.
45. Opinion leaders are more innovative than their followers.
46. Each adopter category is mainly influenced by individuals of the same or a more innovative adopter category.
47. Social system norms on innovativeness seem to determine, at least in part, the innovativeness of opinion leaders.
48. Differences in innovativeness between individuals are a more important barrier to the flow of ideas in a social system where the norms are modern than where they are traditional.
49. The extent of promotional efforts by change agents is directly related to the rate of adoption of an innovation.
50. Commercial change agents are more important at the trial stage than at any other stage in the adoption process.
51. Commercial change agents are more important for earlier adopters than for later adopters at the trial stage.
52. Change agents have more communication with higher-status than with lower-status members of a social system.

It is not difficult to criticize the wording of most of these generalizations in terms of (1) their lack of succinctness and (2) their lack of generality. As an example of the former criticism, consider the generalization that "opinion leaders have higher social status than their followers." In more succinct terms this generalization would be "opinion leadership varies directly with social status." In the case of several generalizations, succinctness was sacrificed for the added clarity of a more lengthy statement.

The lack of general sociological concepts in many of the generalizations indicates these statements are, at best, in the "middle range" and need to approach greater generality before they are considered at the level of general sociological theory. As an example, consider the generalization that "earlier adopters have more specialized operations than do later adopters." Perhaps after further research findings are available from a wider range of contexts, the more general statement may be made that "innovativeness varies directly with specialization."

FUTURE DIRECTIONS

Many specific suggestions for future research were mentioned in each of the preceding ten chapters. At this point, only one further methodological recommendation should be made, the need for "survey experiments" or "field experiments" to test some of the basic generalizations listed in this chapter. There is a limit to what findings from the usual type of correlational analysis of survey data can tell us. For example, little of a cause-and-effect nature about innovativeness can be definitely determined until a research design with a before-after measurement with an adequate control is utilized. There are remarkably few before-after designs with a control that have been used in natural or field conditions, and it is this type of study that offers great promise in testing the present generalizations under more adequately controlled conditions.

This book is actually the first of two volumes. The second volume can perhaps be written in ten or fifteen years after the leads for research suggested here have been followed up and expanded upon.

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27. Schon, Donald A. Technology and Change: The New Heraclitus. New York, Delacorte Press, 1967. 267 pp.

INTRODUCTION

We in the United States, besieged by the continual introduction of new products and processes into our lives, have been quick to accept technological change as a permanent part of our society and as a form of progress. With technological change, we have grown used to technological innovation as a continuing task of established organizations. We have accepted "research and development" as a budget item, an occupational category, a way of life and an inseparable part of industrial and Government institutions. These ideas are well on their way to becoming part of what John Galbraith has called our conventional wisdom.

According to well-established principle, when we accept an idea which was once controversial, we like to forget its origins. We prefer to think of it as eternal. But the idea of technological innovation as an integral part of corporate activity is only about fifty years old. The concepts of "science" and "invention," as we know them, date from the sixteenth and seventeenth centuries. The concept of organized scientific research is derived from the German universities of the nineteenth century. Organized invention seems to have come into being with Edison, around the turn of the century. And fifty years ago the notion that established corporations should hire scientists and engineers and undertake systematic inquiry into their own products, materials and processes, with the aim of improving existing products and processes and developing new ones—the idea of industrial research—was a strange one.

It is one thing for a craftsman to improve his craft. It is one thing to establish a business on the basis of an invention made by an independent inventor. It is quite another thing for businessmen to exploit for business the results of scientific research. It is quite another thing for business to establish a permanent living arrangement with science, and for scientists, technologists and businessmen, with their very different value systems, to enter into a kind of symbiosis quite unknown before the twentieth century.

On still another level it is part of the new conventional wisdom that technological innovation is essential to economic growth and that economic growth—as expressed by rate of increase in Gross National Product—is a sign of national economic strength and vitality. New products create new markets. New processes reduce the cost of existing products, or permit inproved products to be produced without increase in cost, thereby extending markets.

One of our responses to the problem of the balance-of-payments is to think of technological innovation as a way of improving our export/import ratio and fighting off the inroads of foreign competition.

For individual corporations technological innovation has come increasingly to be recognized as a principal—if not the principal—instrument in intercorporate competition. The corporation is seen as a miniature nation: its weapons are products and processes, its battlefield is the market place, its enemies are the corporations with which it competes. Behind its walls it produces weapons and counterweapons, strategies and counterstrategies. On its own level it recapitulates the national belief that technical innovation is essential to the waging of this war, which is the very lifeblood of the firm.

This view, which is by now almost universal in American industry, has swept across industries in waves over, roughly, the last fifty years. What was at first true only of the chemical and petrochemical industries is now accepted doctrine in all but a few industries which have yet to undergo their research cycle.

For individuals, at various levels and stations within the corporation, technological innovation has become a major task and a main road to upward movement. Creativity, for the scientist, engineer and marketing man, and generalship in innovation for the manager, now rank with such traditional corporate virtues as loyalty, steadfastness and financial shrewdness. Increasingly, performance in the corporation has to do, in one way or another, with invention and innovation.

On all these levels of concern with technological innovation, official interests are by no means identical with practice. The nation, industry, firm or individual is not innovative because it favors innovation. According to Galbraith, official talk about innovation stands in innovation's place. As we will be seeing later on, the sources of resistance to technological innovation, at all levels, are enormous. But, again at all levels, the problems concerning innovation are usually defined in terms of getting on with it. Technological innovation is something we strive toward, stimulate, create a climate for, adapt to. Naturally the problems are formulated differently at each level.

At the level of the individual the problem is "how to become more creative" or "how to give inherent creativity more chance to express itself." At the level of the corporation the problem is how to "have more ships at sea," how to "get more out of research," how to "manage innovation" more effectively. For a whole industry the problems have to do with "encouraging innovation in individual firms" or with "becoming more effective in joint technological effort." For the nation as a whole the problems have to do with:

Creating a climate in which industrial technological innovation will flourish;

Encouraging industrial growth, based on innovation, in the regions, particularly the depressed regions, of the country;

Finding ways to help industry meet the challenges of foreign competition and markets;

Coping more effectively with the consequences of technological innovation—the dislocations produced by it; and

Increasing national effectiveness in technological innovation essential to defense and other international contests.

In the following chapters we will try to understand something of the process and problems of technological innovation in the industrial corporation, in industries and in American society as a whole. At each level of analysis, we will find, well embedded in the conventional wisdom, a rational Parmenidean view whose function is to place technological change within a stable state:

A rational view of invention as an orderly, plannable process;

A rational view of innovation as a manageable function of the firm;

A view of technological change as occurring within well-defined industrial boundaries; and

A view of technological change in society as a part of a Technological Program, extending in orderly progress from the eighteenth century to the present time.

But we will also find aspects of the process of technological change which resist these rational models. These include:

the nonrationality of invention;

the nature of innovation as a process of converting uncertainty to risk;

the pattern of interindustry invasion and its consequences;

the undermining of the values of the Technological Program.

The analysis will bear on invention and innovation within the corporation, on a national climate for innovation and on our way of confronting the consequences of technological change.

Accordingly, this book addresses itself first to the process of invention, then to technical innovation in industrial corporations, to patterns of technological change in industry, and finally to the consequences of technological change for our social objectives and norms.

This book is principally about American industry. Insofar as it is concerned with technological innovation, however, it could have focused on other social systems—medicine, for example, or agriculture—whose patterns of innovation have much in common with those of industry. And in its concern with the disruption of the stable state and the need for values for the process of change, it could have centered on other institutions—the family, universities or Government, for example—which share these patterns and needs with industry. The choice of industry as the central theme reflects my own experience. But my effort will be to present the dynamics of industrial change as a metaphor for change in our society as a whole.

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28. Science Policy Research Unit. University of Sussex. Success and Failure in Industrial Innovation: Report on Project SAPPHO. London, Centre for the Study of Industrial Innovation, 1972. 36 pages.

Principal Findings of Project SAPPHO

THE PROJECT

Project SAPPHO is a study of the innovation process in two science-based sectors of industry. It was conceived as a systematic attempt to identify and evaluate the factors which distinguish innovations which have achieved commercial success from those which have not. Existing studies deal almost exclusively with innovations that were commercially successful, although observation shows that in reality attempts at innovation are frequently unsuccessful. It was therefore thought worthwhile to attempt a study of failed innovations alongside parallel successes.[1] There is an abundance of literature on the subject of innovation, largely hypothesising about the conditions under which it flourishes. The hypotheses put forward cover almost every conceivable aspect of the innovation process, and some of them conflict. Typically, studies of innovation have highlighted "single factors" in the process, on which the ultimate success is believed to have hinged. Accepting that innovation is a complex sequence of events, involving scientific research as well as technological development, management, production and selling, it was felt that these single factor interpretations were less than satisfactory, and that allowance should be made for multi-factor explanations. Furthermore, it was considered that insufficient attention had been given to inter-industry differences and that in consequence generalisations had been made that might not apply to all sectors of industry.

THE RESULTS

The results show clearly that the attempt to search for explanations involving more than one facet of the innovation process is justified. The differences observed between the successful and unsuccessful innovations cannot be explained by superiority in any one aspect of the process. To this extent SAPPHO differs from the majority of previous studies. The clear-cut differences within pairs which do fall into a consistent pattern distinguishing between success and failure can be summarised in five statements:

1. *Successful innovators were seen to have a much better understanding of user needs.*—They may acquire this superiority in a variety of different ways. Some may collaborate intimately with potential customers to acquire the necessary knowledge of user requirements. Others may use thorough market studies. However acquired, this imaginative understanding is one of the hallmarks of success. Conversely failures often ignore users' requirements or even disregard their views.
2. *Successful innovators pay much more attention to marketing.*—Failures were sometimes characterised by neglect of market research, publicity and user education, and the failure to anticipate customer problems.
3. *Successful innovators perform their development work more efficiently than failures, but not necessarily more quickly.*—They eliminate technical defects from the product or process *before* they launch it. They usually employ a larger development team on the project, and spend more money on it. This applies even where the successful firm is smaller.
4. *Successful innovators make more effective use of outside technology and scientific advice*, even though they perform more of the work in-house. They have better contacts with the scientific community not in general but in the specific area concerned.
5. *The responsible individuals in the successful attempts are usually more senior and have greater authority than their counterparts who fail.*—In the instrument industry they have more diverse experience, often including experience abroad. The greater power of the individual innovators in the successful attempts facilitates the concentration of effort on the scale which is needed as well as the integration of R&D and marketing.

The results of testing existing hypotheses on the SAPPHO data must be considered in the light of the main finding, that no single factor can by itself explain the success-failure difference. However, some of the previously advanced single factor explanations are supported by inclusion in the group of capabilities that appear to differentiate successful attempts from unsuccessful ones. These include those hypotheses which relate success to market awareness and marketing effort, those which emphasize the importance of individuals, particularly with managerial responsibility, and those hypotheses which relate success to R&D capability and efficiency, and which have stressed the importance of effective communications, both internal and external, in innovating firms. The results do not support the belief that size of firm is a determining factor, that successful innovation results either from strong or weak market positions, that greater familiarity with the technology or the market is a necessary ingredient, or that successful innovators take larger (or smaller) risks than unsuccessful

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[1] An earlier study by the Centre for the Study of Industrial Innovation (*On the Shelf*, 1971) dealt with R&D projects which were shelved. SAPPHO deals with "failures" which were taken a stage further, i.e., reached the point of commercial launch and usually were on the market for several years.

ones. It is encouraging to find that there is broad agreement between these results and those of two earlier studies in other industries, those of Carter and Williams[2] and Marquis and Myers.[3]

The results should not be looked upon as a recipe to ensure automatic success for innovators who apply it. Indeed many of the factors which distinguish success from failure are not of a kind which are easily created within a firm, at least in the short run. An analogy with football may help to clarify the situation. Both in football and in component industrial innovation there will always be winners and losers. This is the nature of the game.[4] Knowledge of those factors which are conducive to success may lead some firms and some football teams to succeed more often than others by applying this kind of knowledge. But their competitors will also learn, so that circumstances are constantly changing and the end-result may simply be an improvement in the standard of "play" all round. The managers of football teams mostly know what their teams ought to do in order to win, but the factors which they are striving to control are not easy to manipulate and they certainly cannot guarantee success in any particular game. What can be much more positively asserted is that a team which has not learned to adapt its tactics and level of fitness to contemporary standards will find itself dropping to the bottom of the League table. To learn the "rules" of innovation management may sometimes lead to well-earned success, depending upon the relative efforts of competitors and an element of chance. Not to know the "rules" or to apply them is likely to have the opposite effect. However, even where no competition is involved, technical and market uncertainties are such that failures will continue to occur.

29(a). U.S. Congress. Joint Economic Committee. U.S. Economic Growth from 1976 to 1986: Prospects, Problems, and Patterns. Vol. 1. Productivity. Washington, U.S. Government Printing Office, 1976, 56 pages. At head of title: 94th Congress, 2d session. Joint Committee Print.

Productivity Trends and Prospects

(By John W. Kennedy)[5]

For more than half a century, productivity advance has accounted for more than half of the growth in real gross national product in the United States. The rest was due to increases in inputs of resources—labor, manmade capital goods, and natural resources—when these are measured without adjustment for quality improvements. But since productive resource inputs have risen little, if any, faster than population, all of our increases in planes of living, defined as real income or product per capita, have been due to productivity advance. It is, therefore, of the utmost importance to pay special attention to the productivity factor in analyzing past economic growth and in assessing prospects for the future.

Looking ahead, I would expect the rate of increase of total factor productivity in the U.S. economy as a whole in the decade 1975–76 to 1985–86 to be somewhat above the 1.7 percent rate of 1966–73. In part, this would reflect the move from cyclically depressed rates of utilization of capacity currently to more efficient rates, assuming 1985–86 is a period of relatively high-level, or even average, activity.

More fundamentally, it reflects the lifting of some of the negative forces affecting productivity in recent years, particularly 1966–70, as reviewed below.

Abstracting from cyclical forces, however, I would expect that the trend-rate of total factor productivity advance in the next decade would be modestly below the 2.4 percent rate of the 1948–66 period. Basically, this would reflect a bit slower growth of R&D: slower productivity advances in extractive industries, and particularly in production of energy materials; and somewhat lesser opportunities for economies of scale as economic growth generally slows down somewhat as the growth of the labor force decelerates in the 1980's. There will be

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[2] Carter, C F and Williams, B R, "Industry and Technical Progress," Oxford, 1957.

[3] Marquis, D G and Myers, S, *Successful Industrial Innovation,* National Science Foundation, 1970.

[4] Circumstances might conceivably be different in a socialist non-competitive economy insulated from the world market.

[5] Professor of economics (on leave), the George Washington University; currently chief economist for the U.S. Department of Commerce.

some offset to these negative factors as the proportion of investments and costs devoted to antipollution, health and safety, and energy conservation stabilize or possibly decline, and as a productivity payoff from these programs emerges.

The rate of increase in output per man-hour in the decade ahead may well equal the longer run trend-rate of somewhat better than 3 percent a year, on average. This more optimistic assessment of prospects for labor productivity relative to total factor productivity is based on the expected retardation of labor force growth in the years ahead. The U.S. Department of Labor projects a 1.2-percent average annual rate for 1980–85, compared with about 2 percent for 1966–73. Assuming that saving and investment propensities are maintained at their past levels, this means that capital per worker will grow significantly faster in the latter part of the decade ahead. Since the rate of increase in output per man-hour is positively correlated with real capital per man-hour, the growth of labor productivity should accelerate relative to the growth of total factor productivity. Thus, real income per worker may be expected to grow in line with past secular trends, assuming that average hours worked per year do not drop faster in the future than they have in the past.

PRODUCTIVITY

(By Edward F. Renshaw)[1]

SUMMARY

In this paper we will first consider productivity from the perspective of such important dimensions of economic and technological progress as speed, scale, and the efficiency of converting energy into useful effects. We will then examine the recent productivity slump and the prospects for further improvements in productivity from the perspective of new technology and such basic economic inputs as labor, capital, energy, agricultural, and pollution control expenditures.

Productivity until fairly recently has been almost synonomous with improvements in output per man-hour. As we near the limits of technological progress, however, it will not be possible to increase one kind of productivity without a sacrifice of some other kind of productivity. In the future much more attention will have to be paid to the productivity of other factors of production such as energy and capital even if it means a fairly substantial sacrifice in the growth of labor productivity. Natural resource scarcity, in the final analysis, is ont only a serious problem at the present time but may very well constitute mankind's most enduring problem. After 2 years of rather inexcusable procrastination Congress has finally passed a major energy bill. While this bill can be considered a step in the right direction, much more can and should be done to encourage energy conservation and to reduce our consumpttion of domestic oil and gas—two of our most valuable and scarcest resources—both of which will be largely exhausted before the turn of this century.

The recent slump in productivity has not only helped to reveal a serious food and energy problem but has also helped to initiate a new and rather virulent type of cost-push inflation which could get worse as the U.S. economy returns to a condition of full employment and productivity again slumps back to a more depressed rate of increase that will gradually decline to zero and perhaps even become negative on the average before the turn of this century.

Our knowledge with regard to how to promote improvements in productivity is rather meager and, in terms of certainty, about on a par with our knowledge of how to control inflation. The large amounts of unemployed resources which now exist in the United States and the high degree of positive association which has existed over time between changes in productivity and changes in total output would suggest, however, that the most effective way to increase productivity in the next year or two will be to adopt those fiscal, monetary, price and wage measures that are likely to be the most effective at reducing unemployment

As one moves from a concern over macroeconomic policy to a consideration of microeconomic measures it seems clear that there are many actions which Congress could take to improve the efficiency of resource utilization. It is rather difficult and perhaps even dangerous to generalize, however, since the various sources of improved productivity are not really independent of each other.

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[1] Professor, Department of Economics, State University of New York at Albany.

Modern aircraft are noted for speed but would never have risen from the ground without the invention of more efficient internal-combustion engines that can be scaled up to an almost unbelievable horsepower rating. Education is certainly important but if additional expenditure for vocational education simply prepared young men and women with outmoded skills for jobs that do not exist it might be counterproductive.

One would hope that additional spending on R. & D. might increase productivity but again one can't be very confident. In the health field the rapid increase in public spending seems to have been much more effective at increasing hospital costs than human life expectancy. It seems clear that we do need substitutes for naturally occurring oil and gas. There is a possibility, however, that the Federal Government's huge prospective investment in new coal gasification technology may have already been rendered obsolete by prospective improvements in electric heat pumps. About all that one can say with confidence is that each and every proposal and strategy for improving productivity must be carefully analyzed on a case-by-case basis.

While the National Commission on Productivity and Work Quality has done a reasonably good job of highlighting areas where productivity can be improved, there is a larger sense in which the promotion of productivity can be considered too encompassing, too complex, and too important to be left to one small Commission. In the remainder of this decade, I would hope that Congress will reexamine all of its own expenditure programs, our national tax system, and the numerous Federal regulatory bodies that may now be inadvertently fostering inefficiency and impeding gains in productivity that are socially desirable.

Since the substitution of one input for another is likely to be of even greater importance in the future than it has been in the past, it would be my guess that the great political controversies of the next decade will continue to center around instances of either too much productivity or not enough of the right kind of productivity. Productivity in the municipal bond underwriting profession, for example, has been so high in recent years as to not provide investors with adequate protection against hidden operating deficits and a rather serious problem of unfunded pension liabilities.

29(b). U.S. Congress. Joint Economic Committee. U.S. Economic Growth from 1976 to 1986: Prospects, Problems, and Patterns. Vol. 9, Technological Change. Washington, U.S. Government Printing Office, 1977. 61 pages. At head of title: 94th Congress, 2d session. Joint Committee Print.

Thinking About Technology Policy for the Coming Decade

(By Nathan Rosenberg) [1, 2]

SUMMARY

The economic conditions which are likely to encourage innovative activity need to be more strongly emphasized. In our recent preoccupation with the contribution of technological progress to economic growth, there has been a serious neglect of the reverse relationship—the contribution of economic growth to technological progress. There seems little doubt that that contribution has been a powerful one in the past—that expectations of high rates of future economic growth have provided highly favorable environments to the willingness of individuals to commit resources to those activities which generate technological progress. Moreover, such favorable expectations have not only influenced the decision to commit resources to inventive activity; they have also positively influenced the *adoption* decision concerning inventions, once such inventions have been successfully developed. New technologies exercise their impact upon the productivity growth of the economy, *not* as a function of the volume of resources committed to the search process or even the actual achievement of new inventions. Rather, that impact is a function of the speed with which the new technology is diffused throughout the economy. New technologies generate productivity growth only to the extent that they are actually incorporated into the economic

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[1] Professor of economics. Stanford University.

[2] I have had the benefit of useful discussions on a variety of relevant matters with Moses Abramovitz. Richard N. Cooper, Stanley Engerman, Victor Fuchs, Hans Mark, David Mowery, Richard R. Nelson, and Raymond Vernon.

life of the society. In this sense it is the decision to adopt which is critical. Such decisions are, in turn, highly sensitive to expectations concernng market conditions and, in particular, to expectations concerning the adequacy of the demand for the product. Innovative activity, therefore, is not likely to flourish in a stagnating or slowly-growing economy with a substantial unemployed or underemployed labor force and an underutilized capital stock. Under these conditions the incentive to undertake inventive activity or to adopt new inventions will be weak and the incentive of workers to oppose the introduction of inventions, especially labor-saving inventions, will be strong. Measures on the macroeconomic level which will assure a sustained high level of economic activity will therefore strengthen both the incentive of business to introduce inventions as well as the willingness of workers to make the necessary accommodations involved in their introduction.

In some respects public policy toward technology may be much more effective if it addresses itself energetically to more modest goals and issues in addition to the big ones. In our preoccupation with the big questions we tend to neglect the fact that there are literally hundreds of things which we can do now, with our present technology, to achieve important goals. For example, while no one of the many ways in which we can, with our present technology, reduce our utilization of fuel, will be highly significant to our aggregate utilization, cumulatively these measures would be enormously significant. Getting people to respond to these present possibilities for fuel savings requires a combination of forceful political leadership together with the willingness to introduce incentives into our economic life to induce people to reduce fuel consumption—smaller cars with less "performance," more extensive use of home insulation materials, substitution of glass bottles for aluminum beer cans, etc. At the same time, recent experience strongly suggests the desirability of a government technology policy involving the development of a greater capacity for shifting to alternative sources of material supplies in various areas, so that we will retain a potential for more flexible policy responses to changing conditions. Such flexibility is likely to be particularly important in activities where long lead times are involved. This necessity is, obviously, likely to become greater in an international environment where access to vital raw materials can be manipulated in response either to political considerations or the prospect of exploiting a monopolistic or oligopolistic advantage in world markets.

A point which requires great emphasis is that technological change and its associated productivity improvements enter the economy through many doors and take a wide variety of forms. Moreover, the location of these doors to shift periodically, so that any rigid mapping of the most significant relationships is bound to become outmoded over time—and not very long periods of time at that. It is of basic importance to the formulation of policy to recognize explicitly his diversity of routes and forms by which technological changes lead to improvements in productivity. Our failure to appreciate this diversity is due to a variety of causes: to the small size of individual improvements, to a frequent preoccupation with what is technologically spectacular rather than economically significant, and to the inevitable, related difficulty which an outsider has in attempting to appreciate the significance of alterations within highly complex and elaborately differentiated technologies. Finally, although we are becoming increasingly aware of the dependence of technology upon science, we are much less aware of the dependence of science upon technology. It needs to be remembered that progress in the realm of science is and always has been highly dependent upon technological improvements which enhance our capacity to observe and to experiment. This is particularly true in the realm of instrumentation. Our present knowledge of the natural world, ranging from microbiology on the one hand to cosmology on the other, would have been inconceivable without the microscope and telescope and the improvements which continue to be made in our observational capacities through further modifications of these instruments.

In spite of the enormous contribution which technological change has made to our economic well-being, it is extremely important that we should not think of it as a potential "fix" for all of our economic problems. The effective formulation of national policies can only be jeopardized by such excessive expectations. This is so not only because we will inevitably be disappointed and frustrated, but because, by placing excessive faith in the prospect for purely technological solutions, we will fail to explore other measures and alternatives which may offer greater, or more immediate, prospects for success.

Technological Change and Future Growth: Issues and Opportunities

(By Joseph F. Contes)[1, 2]

SUMMARY

Over the next three decades we may anticipate major technological advances and changes in American society in the area of electronics, automation, information handling, food, and biological manipulations, as well as in the more commonplace areas of industry, commerce, and domestic devices. Dominant elements driving these changes are fundamental shifts in the availability of energy and materials, which will stimulate major innovation in substitutions, extended service life, and easier maintainability; and the increasing role of science as a wellspring of new technologies. Furthermore, the movement of U.S. society into a post-industrial society with its emphasis on knowledge based industries will stimulate major shifts in the nature and location of work, land use, and information-associated technologies. This will be accompanied by a flourishing of social, institutional, and psychological technologies.

Market forces will play a dominant role in the realization of these new technological developments. In addition to these forces, technological needs and opportunities will arise which lie outside the market system, such as developments with regard to geophysical manipulation, earthquake control, and weather modification.

The principal role of government in assuring continuing benefits from technology is guiding the socially effective interplay of the basic variables: land, labor, capital, resource availability and knowledge. To be socially useful, the interplay must be future-oriented, flexible, and information driven. One specific role for government is setting reliable boundary conditions on private and public endeavors with some clarity and incisiveness to permit market and non-market forces to operate. Put differently, a principal role for government is the more effective management of uncertainties with regard to future potential opportunities and risks in order to encourage new and needed developments and innovations.

A principal limitation on technological and scientific decisionmaking is the inadequacy of knowledge gathered and organized for the purpose of illuminating public policy. Meeting these information needs is a second specific role for government. Since most information is collected for other purposes, modifications which explicitly generate and collect policy-related information would effect a major improvement in public and private decisionmaking.

The wider practice of the concept of technology assessment as a means to better understand options, alternatives, and consequences for technology should be encouraged in and out of government.

Many major regulatory agencies of government reflect needs and problems decades old which are no longer of primary importance. A third specific role for government in guiding technology, the reform of the regulatory agencies through their restructuring, offers major opportunities for more effective management of technology. Primary candidates for this specific role of government include agencies regulating communications, drugs, banking, securities, energy, health care, transportation, and marine and oceanographic affairs.

The fourth major role for government, research and development, should be driven by several convergent factors. There are opportunities for new and expanded technological developments with regard to: (*a*) The wiring of metropolitan and rural areas for fuller telecommunications; (*b*) the introduction of major new energy sources such as solar, geothermal, and ocean technologies; (*c*) the reformulation of education technologies, welfare, and health delivery systems; and (*d*) the reconstruction of cities and other habitats. Furthermore, the economically mature society implies not less but different technology emphasizing: social and biological as well as physical technology; personal improvement and fulfillment, and accomplishing more with less. There are also numerous problems of a high-growth society such as the propensity to maximize bureaucratic efficiency at the expense of social effectiveness; alienation of workers; adverse effects of excessive size and integration; societal needs not accommodated by market forces, and the negative side effects of technology. Each of these clusters of problems and opportunities could be profoundly influenced by research and experimentation.

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[1] Assistant to the Director, Office of Technology Assessment, U.S. Congress.

[2] The material in this paper is the responsibility of the author and does not represent the position of any government agency or the U.S. Congress.

30. U.S. Congress. Joint Economic Committee. Subcommittee on Priorities and Economy in Government. Priorities and Efficiency in Federal Research and Development: A Compendium of Papers. Washington, U.S. Government Printing Office, 1976, 115 pages. At head of title: 94th Congress, 2d session. Joint Committee Print.

The Relationship Between Defense-Related and Civilian-Oriented Research and Development Prioritiees

(By Lester C. Thurow)

X. Conclusions

There are a variety of actions that could be taken to strengthen the system of research and development in the United States.

(1) Research and development expenditures should be broken into three broad categories—basic capabilities, mission orientated, and massive mobilization.

(2) Funds for basic capabilities should be spent on analysis of how much it costs to keep enough R. & D. personnel in an area to be aware of any breakthroughs that might occur and to be able to expand rapidly should each breakthrough actually occur. Instead of allocating funds to traditional disciplines, funds should be allocated across life sciences, agricultural sciences, environmental sciences, material sciences, energy sciences, behavior sciences, logical sciences, space sciences, and equipment sciences.

(3) Funds for mission oriented research should be spent based on the modified cost-benefit analysis outlined above. Every project should have ranges of possible benefits and costs along with an estimate of the maximum possible benefit. Wherever possible there should be ranges of costs and benefits estimated by more than one individual or group. Since it is not possible to make analytical comparisons across non-commensurate objectives, mission oriented research should be broken into four types—national independence, life saving, economic goods and services, and non-economic quality of life goods and services.

(4) Massive mobilization research will be funded in accordance with whatever is necessary to achieve the goal over time and in accordance with efficient expenditure rates at any point in time. But massive mobilization research will seldom occur and it will never occur if the basic scientific knowledge does not exist to be relatively confident of success within a 5 to 10 year time period.

(5) Spinoffs and economic multipliers should always be ignored in allocating R. & D. expenditures.

(6) Institutional constraints need to be taken into account in allocating R. & D. expenditures. Unless you are going to improve railroad roadbeds there is no sense in spending money on developing fast trains.

(7) Some procedure must be developed to overcome the learning curve externality in the non-military non-medical part of the R. & D. budget. The best technique would probably be to continue public R. & D. expenditures further along the development path but to them insist that all production data and processes be made publically available.

(8) Cost-reduction R. & D. is probably being slighted in favor of new product R. & D. Here again the problem can probably only be solved by changing the current de facto proprietary rights of those who might be hired to do the cost-reduction research. Whatever information is generated must become much more publicly and quickly known if this research is to overcome the political obstacles that it currently faces.

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Senate Procedures for Authorizing Military Research and Development

(By Louis Fisher)

IV. Conclusions

Members of the Senate Armed Services Committee have spoken openly of their need for adidtional assistance. During hearings in 1969 Senator Barry Goldwater stated that the Committee lacked time to scrutinize Pentagon requests: "We need help on it."[64] Staff members who presently assist the R&D Subcommittee speak candidly of the frustration they feel in trying to discover an adequate handle to analyze budget requests.

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[64] *The Military Budget and National Economic Priorities* (Part 2), hearings before the Joint Economic Committee, 91st Cong., 1st Sess., 471 (1969).

Frequently it is proposed that Congress acquire additional staff capability. CED, for example, recommends that Congress estabilsh an office to assist in the review of the defense budget and weapons programs.[65] Such proposals are received skeptically by the congressional staff presently responsible for defense authorizations. Recent years have brought a dramatic increase in legislative staff, including the greatly augmented responsibilities of the General Accounting Officee and the Congressional Research Service, the new Office of Technology Assessment, and the resources available from the newly created Budget Committees and the Congressional Budget Office. The feeling runs deep that Congress, at least for the time being, has reached a saturation point.

Assistance at this point must come in a form that eases the burden and simplifies the task. Whether studies are conducted by existing staffs, a new permanent office, or a temporary commission, there must be appreciation and sensitivity for the intense schedule that already presses upon congressional committees. While the number of reports and analyses may climb without limit, the day remains fixed at 24 hours.

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Some Observations on the Effectiveness of Federal Civilian-Oriented Research and Development Programs (FC/R. & D.)

(By Albert H. Rubenstein)

5. CONCLUSIONS AND RECOMMENDATIONS

The issue of measuring or even qualitatively assessing the effectiveness of Federal Civilian-Oriented R. & D. (FC/R. & D.) is far from a matter of merely collecting existing data and performing some statistical analysis to see if the output justifies the input. There are some severe conceptual. measurement, and value problems that must be addressed before such measurement or assessment can be done effectively.

Conceptually, the problems involve an analysis of the total R. & D./Innovation process, including its involvement with the social subsystems and supersystems which it is intended to serve or which it serves inadvertently. This means that the various stages of outputs described in this paper require careful study and differentiation in terms of what credit (or blame) the R. & D. part of the process deserves for its contribution. Then there is the related issue of accounting for the other important inputs to the social systems, including political as well as economic inputs. This is crucial, since political and administrative decisions on whether and how to stimulate or inhibit the flow of the innovation process from laboratory to user play a decisive role in whether any ultimate results are achieved.

Measurement problems are also severe for a number of reasons. One is that the entities or events which constitute the potentially measureable output of the R. & D./Innovation (R. & D./I) process vary widely in size, form, detectability, directness, and other characteristics. Decision on a unit of measurement is a task that has defied many efforts over the past few decades to assess the outputs of the R. & D./I process. Given that some units can be agreed upon (e.g., number of new products in the intermediate stages or increase in employment at more ultimate stages of the total process) there is the fundamental problem of imputing to a given input in this complex process the proper quantitative share of credit for outputs from the overall process or the various stages in the process. This is particularly important in a process such as R. & D./I, where many inputs are necessary to achieve useful results and none of them is sufficient to achieve them alone.

Finally, the value questions are perhaps as complex and ill structured as the measurement and conceptual problems. To what extent is the society willing to spend federal funds to support and encourage a process which has the potential. in addition to helping society at large, for helping some individuals and organizations to benefit greatly from involvement in it (e.g., the entrepreneurs and the venture capitalists). Is the society willing to have funds earmarked for a particular social mission contribute to outputs in another sector. If the answers to these value questions are affirmative, then the budgeting, planning, programming, management, and incentive structure of our FC/R. & D. programs should be made consistent with these values.

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[65] Committee for Economic Development, *Congressional Decision Making for National Security*, September 1974, at 24.

These comments lead to a few specific recommendations which are in an area of joint decision and action by Congress and the Administration:

1. Clearer guidelines should be established and enforced on how far along the R&D/Innovation continuum (lab to market place) the Federal Government is willing and able to encourage and influence the R&D/I process
2. If further real involvement in the process is desired on the part of Federal civilian agencies, the legislation, regulations, funding, and reward structure should reflect these desires.
3. Instead of an occasional investigation or quick inquiry into the effectiveness of the FC/R&D process in producing useful outputs for society, a continuous, systematic audit[8] should be established to provide guidance on how the R&D/I process is working in various sectors and what changes are needed to make it more effective.

None of the recommendations mentioned above can be easily done with the flick of a wrist or the announcement of intentions. The size and complexity of the system, with all its inherent uncertainty and time lags, requires that a well-funded, competently-staffed effort is needed to specify the exact changes that are needed in regulations, legislation, operating procedures, and innovation climate to increase the effectiveness of FC/R&D. Clues to many of the factors involved are given in this paper, but their incorporation into a workable pattern will take a lot of hard work over an extended period, if the situation is to be improved significantly. As a result of the many experiments and studies supported by the ETIP program of the National Bureau of Standards and the RDI program of the National Science Foundation, there is much information accumulating on the barrier to improved effectiveness of FC/R&D. This information needs to be sorted out, integrated, and utilized in improved design of the process.

The Relationship Between Federal, State, and Local Government Support for Research and Development

(By William D. Carey)

Conclusions

Research and development are, at the present time. peripheral aspects of intergovernmental relations. Trace elements of the massive Federal involvement in science and technology can be detected in the operations of State and local governments, and patches of State and local awareness and activity appear here and there are exceptions to the general picture of low R&D vitality. Through the persistence of the National Science Foundation, however, the institutional capabilities of State and local government for coping with scientific and technical aspects of problems of choice have been significantly upgraded.

Where to go from here is the tough question. Throwing R&D dollars at State and local governments as an impulsive act of faith cannot be justified as a policy choice. The flow of general revenue sharing has turned up no evidence that State and local decisionmakers viewed investment in R&D as a priority use of discretionary revenues. The managerial capacity of most State and local governments for planning and executing R&D are not such as to inspire high confidence.

The assumption continues to be workable, however, that the pyramiding dilemmas and frustrations of State and local government can be relieved if the R&D resources of the Federal Government can be coupled in a productive way with the State and local users. This writer believes that if *process* is emphasized as the key to intergovernmental relations in R&D a productive role for State and local governments can be carefully worked out over time. We have been emphasizing the wrong things—R&D as a self-fulfilling prophecy. State and local spending on R&D, and technology transfer as a species of Federal surplus proprty disposal. We do not have much to show for it to date, nor any reason to expect better results in the future.

If the objective is to expedite and increase the diffusion of know-how and technology through intergovernmental arrangements, some barriers will have to come down and some catalysts be provided. One barrier is the idea that "R&D" means high technology; in the case of State and local government it is more likely to mean low or intermediate technology. A second barrier is the sparse representation of State-local operating experience in Federal R. & D. agencies. A third is the lack of incentives for Federal agencies to assign strong weights to State and local needs and preferences, relative to Federal mission requirements, in shaping R. & D. programs. A fourth is the poor-to-moderate capacity of many State and local governments for judging the risks and benefits of applied science and technology, and the inadequate resources of National Science Foundation for improving their capacities. And a fifth barrier is the resistance at the Federal level to making the technical services of its laboratories and technology centers generously available to State and local governments for joint R. & D. and problem solving.

In the long run, the largest benefits of Federal R. & D. will result from enabling State and local governments to exercise meaningful leverage on the Federal Government's outlays for R. & D. in the civil areas. If this is going to happen, a process must be introduced which gives the States and localities an effective voice in programing. This requires leadtimes of 1 to 3 years, and even longer waiting times for the results to be evaluated and put into practice. If this does not come as good news, there is no help for it. R. & D. have time cycles which must be understood, even by elected officials who want answers in time to impress the voters. Intergovernmental relations in R. & D. are different from other kinds of intergovernmental relations, and the reason for it is found in the built-in uncertainty of research and development. Perhaps this has a lot to do with the unimpressive performance of R. & D. as a fast-response remedy to social problems. Put very simply, R. & D. comes under the head of *investment*, not current expense. By leveraging the Federal investment, State and local governments can expect deferred but potentially high yields.

In the shorter run, intergovernmental policy strategies should emphasize a variety of catalysts for the diffusion of R. & D. into and among State and local governments. Primary among them is the strengthening of know-how and analytical capacity in the Governors' planning offices and in the legislatures. of State Legislatures, regional cooperative consortiums of States and cities, and providers, such as the Science and Technology arm of the National Conference of State Legislatures, regional cooperative consortiums of States and cities, and PTI, are solid candidates for further support and diverstification with the role of the National Science Foundation being augmented by ERDA, EPA, and HEW. The potential of the Federal R. & D. centers as catalysts for technical assistance should be recognized and legitimized as a strong and geographically dispersed capacity in-being for regional public service. Taken together, these combined actions would constitute a pragmatic and low-cost start towards assembling the elements of an intergovernmental relations strategy for R. & D.

Federal Support of R. & D. Activities in the Private Sector

(By Edwin Mansfield)

14. Summary and Conclusions

In conclusion, the federal government supports R. & D. in the private sector in a variety of ways. In 1974, the federal government financed about $8 billion of R. & D. carried out by firms, about $3 billion of R. & D. carried out by colleges and universities, and about $1 billion of R. & D. carried out by other nonprofit organizations. (Of course, some recipients, such as State universities, are not in the private sector.) Much of the R. & D. performed by the private sector for the federal government is directed toward technological change in public goods like defense and space exploration, not toward private-sector problems. The rationale for federally financed R. & D. directed at private sector problems is generally that the private costs and benefits from R. & D. do not adequately reflect the social costs and benefits. Besides its contracts and grants, the federal government also supports and encourages private sector R. & D. through the patent laws, the tax laws, some aspects of regulation, the antitrust laws, federal programs to transfer technology, and its educational policies. There is no way to put an accurate dollar figure on the amount of support from these activities.

Due to the inappropriability, uncertainty, and indivisibility of R. & D., an under-investment in R. & D. may occur in the private sector. But this may be offset, partially or fully, by oligopolistic emphasis on nonprice competition, by existing government intervention, or by other considerations. Based on simple methods, economists have attempted to estimate social rates of return from various kinds of investments in R. & D. and technological innovation, both in agriculture and industry. The results seem to suggest that both the marginal and average social rates of return have been very high, and many economists have interpreted these results as evidence of a possible under-investment in R. & D. However, these estimates suffer from many important limitations, and should be viewed with caution.

There are a variety of ways that the government might stimulate additional R. & D. in the private sector—tax credits, R. & D. contracts and grants, expanded work in government laboratories, loan insurance for innovation, purchasing policies with greater emphasis on performance criteria and life cycle costing, altered regulatory policies, and prizes. An important problem with a general tax credit is its inefficiency; an important advantage is that it involves less direct government controls. An important problem with more selective support mechanisms is that it is so difficult to estimate in advance the social benefits and costs of particular types of R. & D. projects. In my own opinion, if a program of this sort were started, and combination of selective and more general forms of support would be most effective.

Although many economists suspect that there may be an under-investment in certain areas of civilian technology, there is at the same time some concern that the federal government, in trying to improve matters, could do more harm than good. In this regard, it seems to be generally agreed that any selective program should be neither large-scale nor organized on a crash basis, that it should not be focused on helping beleaguered industries, that it should not get the government involved in the latter stages of development work, that a proper coupling be maintained between technology and the market, and that the advantages of pluralism and decentralized decision-making be recognized.

In previous sections of this paper, I have discussed (all too briefly) a variety of policy alternatives that have been suggested for improving the existing federal posture concerning civilian technology, as well as the broad issues that bear on the relative desirability of many of these policy alternatives. Perhaps the most important point to emphasize in this connection is the extent of our ignorance and uncertainty. There sometimes is a tendency to slur over—or perhaps not to recognize—the fact that very little really is known concerning the effects of many of these policy alternatives, or concerning the desirability of their effects. (Indeed, in some areas, no one really knows how to study these questions effectively, let alone provide answers here and now.) Given the current uncertainties, it would seem wise to proceed with considerable caution, and to build into any program the capacity and necessity to resolve many of the key uncertainties before too big a commitment is made.

Finally, it is important to recognize that the nation's basic economic policies may have a notable impact on R. & D. and technological change in the private sector. Technology policy, after all, must be integrated with and viewed in the context of, our overall economic policy. With regard to antitrust policy, which is an important element of our basic economic policy, the available evidence does not indicate that we must permit very great concentration of American industry to achieve rapid technological change and the rapid adoption of new techniques.

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31. U.S. Department of Commerce. Commerce Technical Advisory Board. The Role of New Technical Enterprises in the U.S. Economy. Washington, 1976, 13 pp.

(By Richard S. Morse)

III. Recommendations for Corrective Action

As observed in the 1967 CTAB report on technological innovation, the entrepreneurial process, particularly as it relates to high technology companies, is not well understood. It has been noted, however, that the process can occur only in a favorable environment. This environment has deteriorated over the last few years in the following manner:

1. Government R. & D. programs are a less significant factor in stimulating high technology companies. The character and complexity of government procurement

policy and procedures and its management methods have resulted in a significant deterioration of the effectiveness of these programs in stimulating these companies.

2. Financial incentives for the entrepreneur and the investor have declined.
3. Government regulation has greatly increased the operating cost and management problems of new business enterprises.
4. The liquidity of investments in small companies has been reduced by the absence of a receptive public market and by regulation.
5. The supply capital for starting new high technology ventures is almost nonexistent. Private capital for seasoned new companies is difficult to obtain and public financing is essentially unavailable.

These changes in the entrepreneurial environment present a serious problem for the U.S. conditions as they exist today, new high technology growth companies are not being organized in sufficient numbers to provide the jobs and the technically-advanced products for domestic consumption and export which will be needed in the decades ahead. If the future economic health of the country is to be insured, it is apparent that steps must be taken to improve the business environment. It is probably impossible to predict quantitatively the extent to which any specific legislative or administrative change might stimulate or expedite the generation of new business enterprises. Nevertheless, the following *recommendations* are suggested for executive and legislative action with the expectation that these actions would enhance the initiation and growth of new technically-based enterprises:

1. *Change Capital Gains Tax.*—A reduced capital gains tax rate for direct investment in small technical enterprises should be an effective incentive to make venture capital available for "start-ups." Such an incentive should be available to both corporate and individual investors.
2. *"Founders'" Stock.*—A new mechanism is needed to facilitate the acquisition of "Founders'" stock by officers, directors, and key employees during the formative years of a company. Care should be taken to prevent adverse tax consequences which negate the value of the stock in attracting key talent to the enterprise team.
3. *Recognize the Role of Corporate Investors.*—The institutionalization of the venture capital community and the increasing use of the industrial corporate venture mechanism suggest that it would be desirable to allow corporate participation under both Sub-Chapter S and Section 1244 of the Internal Revenue Code.
4. *Tax Incentive for Direct Investment in Small Technical Enterprises.*—An immediate deduction against income for individual, institutional and corporate investors for their direct investment in small technical enterprises would be an effective incentive for start-up financing. The investors would assume a zero base, and capital gains tax liability would be incurred only upon sale of the investment.
5. *Review SEC Rules.*—SEC rules, notwithstanding Rule 144, continue to restrict the small-company-investor's liquidity. New combinations of holding periods and rates of distribution (for both private and public companies) should be considered.
6. *Review Reporting Procedures.*—Reporting requirements under the rapidly growing state and federal regulations should be reviewed with the intent of simplifying the requirements for small companies.
7. *Review Tax and SEC Regulations.*—General cost increases and inflation have made dollar limits in certain rules too small. In particular, for 1244 stock, the maximum asset value should be increased to $1,000,000; the loss allowance should be increased to $50,000 on an individual basis, and $100,000 on a joint return basis. Similarly, the capitalization limit for a Regulation A registration should be increased to $1,000,000. The small business 22% tax rate should be applied to the first $100,000 of income rather than $25,000. The tax-loss carry-forward period should be extended from five years to ten years.
8. *Review Incentives for Management.*—For the new enterprise, the value of stock options as a management incentive can be restored by reducing the holding period for shares issued under a qualified plan and by arranging to defer tax liability for shares issued under a non-qualified plan. Other forms of financial and tax incentives should be developed for the management and key employees of the higher-risk new technical enterprise.

32. U.S. Department of Commerce. Office of the Assistant Secretary for Science and Technology. U.S. Technology Policy: A Draft Study, Washington, 1977, 171 pp.

EXECUTIVE SUMMARY

Introduction

This paper discusses U.S. technology policy in its relationship to the Nation's economic welfare and makes specific recommendations for an improved policy.

The goal of U.S. technology policy should be to maximize our capacity to develop and utilize technology for national purposes. Market economic criteria alone are not adequate for making social choices and for determining the national goals which technology policy should help achieve. Many non-economic factors are important in formulating a national technology policy, including the protection of the ecological system, the quality of employment, and the effects of technology on life styles. A comprehensive discussion of these important non-economic factors is outside the scope of this paper.

Since technology is a pervasive force throughout society, it is affected by a large variety of Government actions. In the context of this paper, U.S. technology policy is the sum of actions taken by the Federal Government affecting the production, diffusion, and utilization of technology. The elements comprising the policy lack unity and coherence. The pluralistic development of U.S. technology policy has resulted in a national technology enterprise with considerable strengths. But the fragmentation, incoherence and sometimes contradictory aspects of the various elements of the policy hold some disadvantages for the U.S., particularly in a world no longer dominated by U.S. technology.

Background

CONTRIBUTIONS OF TECHNOLOGY TO U.S. ECONOMIC DEVELOPMENT

It has been estimated that technological innovation was responsible for 45 percent of the Nation's economic growth between 1929 and 1969.

A comparison of technology-intensive manufacturing industries with other industries in the period 1957–1973 shows that:

Technology-intensive industries grew 45 percent faster;

Employment in technology-intensive industries grew 88 percent faster;

Productivity in technology-intensive industries grew 38 percent faster; and

The ratio of price to unit output increased 44 percent less in technology-intensive industries.

DISQUIETING TRENDS

Recently, some disquieting trends have appeared in the Nation's inventiveness, entrepreneurship, productivity, and international trade:

The U.S. share of patents filed worldwide and the number of U.S. patents awarded to U.S. nationals has decreased in the last decade.

The number of innovative technology-based companies that are starting in the United States is much less than a few years ago.

The U.S. worldwide lead in productivity, measured as GNP per civilian employee, has narrowed by 50 percent since the 1950's, and current U.S. productivity growth is below its historical trend.

The Nation's large favorable balance of trade in products of R&D-intensive industries has come to depend primarily upon exports of developing countries and Canada.

We cannot establish definite relationships between the disquieting economic and technological trends, or even agree on how "disquieting" they are. Nevertheless, the trends are serious enough to require that U.S. technology policy be studied to identify weaknesses and opportunities for improvement. That study is the subject of this paper.

Contradictory Elements of Current De Facto Policy

In this paper the elements of the current technology policy are discussed under the following headings:

Production of technology,

Diffusion and utilization of technology in the domestic economy, and

Diffusion and utilization of technology internationally for achieving foreign policy objectives.

The elements pertinent to each of these areas are set forth in terms of concerns and possible alternative remedial actions in the appendix to this summary. Many of the actions are not mutually exclusive.

Many of the elements are contradictory in their efforts on innovation:

The innovation incentive of patent protection is undermined by compulsory licensing.

The support of long-range and undirected basic research is called for at the same time that the "Mansfield Amendment" restricts DoD to mission-oriented research.

Government-industry cooperation in large R&D projects of national concern is promoted at the same time that Federal patent policy discourages this cooperation.

Cooperative industrial R&D on high risk, expensive projects to alleviate national problems is desired, but is discouraged by antitrust attitudes.

Technological innovation is called for at the same time that tax and regulatory barriers are erected to innovation.

The economic benefits of exporting technology-intensive products are desired at the same time that overly restrictive controls on exports are imposed.

RECOMMENDATIONS FOR AN IMPROVED NATIONAL TECHNOLOGY POLICY

A coherent national technology policy needs to be developed in order to maximize the U.S. capacity to develop and utilize technology to achieve national purposes. The solid definition of, and reasonable degree of continuity in, consistent Federal technology policy would promote private sector investment in technological innovation.

Several of the actions discussed in the appendix of this summary are new to the United States and, in our opinion, necessary to the formulation of a coherent policy, while others can be implemented by continuation and/or straightforward expansion of ongoing programs. We recommend that eight particular areas should receive priority attention in order to achieve the economic gains a coherent policy would foster:

INDUSTRIAL TECHNOLOGY ANALYSIS OFFICE (APPENDIX D, I)[1]

Every proposed national policy, whether or not obviously technology related, should be evaluated for its potential impact on technology. The means for such analyses are lacking. An industrial technology analysis office should be established immediately in the Department of Commerce. This offiice would evaluate proposed U.S. Government actions against the goal of U.S. technology policy to maximize the capacity to create and utilize technology for accomplishing national objectives. It would perform analyses of technico-economic indicators related to economic and industrial growth and productivity; technological factors in foreign trade and direct foreign investment, including costs and benefits of technology transfer; resources (manpower, capital, etc.) applied to the generation and acquisition of technology; effectiveness of various governmental policies in promoting the Nation's technological health; legal, regulatory, institutional and other barriers to technological innovation; and social cost-benefits of currently debated or anticipated major technological developments.

INDUSTRIAL R&D (SECTION III, A)

Some types of industrial R&D of high potential social value are not being performed because the economic rewards to individual companies are not great enough and the risks and costs are too high. The Federal Government should investigate direct (grants, loans, etc.) and indirect (tax, regulation, etc.) means of promoting the needed technological innovation in the private sector.

MODIFICATION OF REGULATORY INHIBITIONS OF INNOVATION (SECTION IV, A, 1)

The present regulatory climate contains unnecessary disincentives for technological innovation. Under the Office of Science and Technology Policy leadership, actions should be undertaken to strengthen the required data base, and to develop more appropriate mechanisms for deciding on acceptable risks and developing optimum regulatory strategies. Also, more adequate assessments of the probable impacts on technological innovation, as well as costs vs. benefits of such regulatory strategies, are needed.

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[1] These references cite the relevant part of the full report.

IMPROVING THE CLIMATE FOR STARTING TECHNOLOGY-BASED ENTERPRISES (SECTION IV, B)

The U.S. economy is losing a traditional growth stimulus because the present tax and regulatory climate is not conducive to the start-up of new advanced-technology companies. The Departments of Commerce and Treasury should work with the Securities and Exchange Commission to investigate a variety of possible remedial actions.

INNOVATION INFORMATION FOR STATE AND LOCAL GOVERNMENTS (SECTION IV, C, 2)

The present scattered Federal Government pilot programs aimed at providing innovation information to state and local governments are not adequate to supply the needs and to capitalize on the potential for productivity increases in these sectors. The existing demonstration projects should be administratively consolidated and strengthened.

EXPORT PROMOTION OF TECHNOLOGY-INTENSIVE PRODUCTS (SECTION V, A)

The economic benefits of technology-intensive products exported from the United States are being less and less fully realized. Additinal foreign markets must be developed for nonmilitary technology products. This is especially necessary to create employment opportunities to compensate for those that may be lost if foreign military sales by U.S. aerospace and defense-related industries are reduced. The Government should work wih industry to streamline further the various export control procedures and reporting requirements, to shorten the list of commercial products or technical data requiring specific permission to export, to continue reducing delays n the various export licensing processes, to improve efforts in market identification and analyses for technology-intensive products, to develop better Federal promotional practices, and to improve the relevant financing policies to be more competitive with foreign countries.

EXPORT CONTROL OF DESIGN AND MANUFACTURING TECHNOLOGY (SECTION V, B)

Export control involves the Departments of Commerce, State, Defense, as well as the Energy Research and Development Administration, NASA, the Nuclear Regulatory Commission, the National Security Council, and the Intelligence Community. A recent turnabout in Defense thinking, increased concern of the Congress, and new attitudes on arms exports and nuclear proliferation indicated by the Carter Administration have created the need and opportunity for a greatly improved policy. There is no satisfactory interagency means for addressing these issues, nor is consultation with industry any better. Both Commerce and Defense have elaborate committee structures that are foundering because top-level leadership is lacking. The Executive Office of the President, through the OSTP or the NSC, should assume leadership in developing an export control and technology transfer policy which better serves both U.S. national security and economic interests.

TECHNOLOGICAL SUPPORT OF LESS-DEVELOPED COUNTRIES (LDC'S) (SECTION V, C)

Technology issues relevant to LDC's have been receiving too low priority. An unsound policy in this field could have very large adverse impacts on the economy and on foreign relations. A U.N. Conference on Science and Technology for Development in 1979 requires the establishment of a U.S. policy which contributes to the progress of LDC's while being consistent with U.S. interests. The Departments of State and Commerce should work closely with industry to promote cooperation in industrial R&D and to assist technological infrastructure development in LDC's.

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33. U.S. National Science Board. Science Indicators 1976. Washington, U.S. Government Printing Office, 1977. 312 pp. (NSF-77-1).

International Indicators of Science and Technology

INDICATOR HIGHLIGHTS

The relative emphasis placed by a country on research and development activities can be approximated by comparing its R&D expenditures to its Gross National Product (GNP). During the middle and late 1960's, and continuing into the early seventies, this ratio generally showed a decline for the United States, the United Kingdom, France, and Canada. The West German ratio peaked in 1971 and now appears to be declining. The U.S.S.R.'s positive growth seems to have leveled off since 1973.[1] Since the late 1960's, Japan has generally shown increases in its R&D/GNP ratio.

Another comparative measure of a country's R&D effort is the relationship between the number of scientists and engineers (S&E's) and the population. The number of S&E's per 10,000 population in the United States has remained constant since 1972. The 1975 level is 10 percent lower than that of 1969, when this ratio peaked in the United States. Limited data from the other countries studied showed a general increase in this ratio.

A major difference between the R&D programs of the United States and other countries relates to the distribution of Government funds by function. Among the countries for which data are available, the United States devotes a much higher proportion of Federal R&D funds to defense and space-related activities, especially the former.[2]

The United States contributes significantly to the world's scientific and technical knowledge base. Non-U.S. authors cited U.S. scientific publications 15 percent more in 1975 than could be expected from the U.S. share of the world's scientific literature—citations to U.S. chemistry, physics, and biomedical research publications were respectively 42 percent, 30 percent, and 26 percent more than could be expected.

The United States also utilizes other nations' scientific findings and journals. In 1975, 57 percent of the citations appearing in U.S. chemistry publications and 49 percent of those in U.S. physics publications were to foreign publications. Those fields with the greatest percentage of articles appearing in non-U.S. journals in 1975 were mathematics and biomedical research (both 27 percent) and physics and chemistry (both 24 percent).

Since 1961, U.S. scientists have received 53 percent of the Nobel Prizes in physics, 36 percent in chemistry, and 53 percent in physiology/medicine. This represents 47 laureates or 24 percent more Nobel Prize winners in science than during the 1946–1960 period. While U.S. scientists received all of the Nobel Prizes awarded in 1976, the U.S. share of total prizes has remained at about 50 percent since 1946.

Although positive, the U.S. patent balance declined almost 47 percent between 1966 and 1975. This was due to the 91 percent increase of foreign-origin patenting, coupled with the leveling off and eventual decline in the number of foreign patents awarded to U.S. citizens. The United States has a favorable but declining patent balance with Canada, the United Kingdom, and five European Economic Community countries, but a negative balance with West Germany and Japan.

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Resources for Research and Development

Indicator Highlights

National research and development (R&D) expenditures in the United States rose to an estimated $38.1 billion in current dollars in 1976; however, constant dollar spending of $28.5 billion was only 2.5 percent above the 1974 total.

The estimated number of scientists and engineers (full-time-equivalent) engaged in R&D reached approximately 531,000 in 1975, slightly higher than the 1974 total but still far below the 1969 level of 558,000.

As a fraction of the Gross National Product (GNP), national R&D spending has dropped from the high of 2.97 percent reached in 1964, falling to an estimated 2.25 percent in 1976. Estimated Federal funds for R&D in 1976 as a fraction of GNP reached 1.19 percent, while funds from all other sources remained near 1 percent.

Measured in current dollars, estimated Federally-supported R&D expenditures climbed to a new high of $20.1 billion in 1976; however, constant dollar levels stood at $15 billion, 18 percent below the peak reached in 1967.

The Federal Government remained the largest source of R&D funds in 1976, providing an estimated 53 percent of the total, while industry supplied 43 per-

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[1] Data regarding the U.S.S.R. should be treated as estimates; limited information and differences in basic definitions make international comparisons involving the U.S.S.R. very difficult. (See the following text for discussion of this point.)

[2] Data for the U.S.S.R. are not available.

cent; in contrast, Federal sources provided 65 percent in 1965 to industry's 33 percent.

R&D funds from industrial sources rose considerably in the period from 1960 to 1976, from $4.5 billion to an estimated $16.6 billion. In constant dollars, these industrial R&D expenditures reached a new high of $12.4 billion in 1976.

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Resources for Basic Research

Indicator Highlights

National spending, in current dollars, for basic research climbed substantially since 1960, and rose to a new high in 1976; in constant dollars however, estimated expenditures in 1976 advanced approximately 2 percent above the 1975 level, but remained nearly 11 percent below the peak year of 1968.

Among performers of basic research, more than half of the Nation's expenditures were accounted for by universities and colleges in 1976, compared to a 37 percent share by this sector in 1960. Industry held an estimated 16 percent (half of its 1960 share) in 1976; the Federal Government also held 16 percent in 1976.

The source of most support for basic research was the Federal Government in 1976, as it has been in past years. The Federal share has amounted to 68 percent of the total since 1971, compared with approximately 60 percent in 1960; the share of support provided by industry has remained stable at approximately 15 percent throughout the 1970's, in sharp contrast to the 28 percent share this sector provided in 1960.

In constant dollars, estimated Federal and industrial support for basic research in 1976 was 15 percent below the peak levels which each had reached in 1968. Real dollar support by each of these sectors has remained at about the same level between 1974 and 1976.

Six agencies—HEW, NSF, ERDA, DOD, NASA and USDA—obligated over 90 percent of Federal basic research funds in 1976. Current dollar obligations by these six agencies have increased 32 percent in the period 1967–76.

Federal obligations for basic research in the life sciences, environmental sciences, engineering, and social sciences, reached their highest current dollar levels in 1976. However, constant dollar obligations in all fields were lower than in previous years.

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Industrial R&D and Innovation

Indicator Highlights

It is estimated that the total expenditure for R&D in industry was $26.5 billion in 1976, up 9 percent over the 1975 estimate and 2½ times the 1960 level. The 1960–76 increase resulted primarily from increases in industry's own R&D funds.

When measured in constant dollars, total industry R&D spending is expected to show a 4-percent increase between 1975 and 1976. This marks the first increase in constant-dollar industrial R&D expenditures since 1973.

In January 1975 there were an estimated 357,500 R&D scientists and engineers employed by industry. This number has remained level since 1973 but is down nearly 8 percent from the 1969 high of 387,100. The entire decrease since 1969 can be attributed to a drop in the number of federally supported R&D scientists and engineers.

Six industries accounted for over 85 percent of all industrial R&D spending in 1974. They were electrical equipment and communication, aircraft and missiles, machinery, motor vehicles and other transportation equipment, chemicals and allied products, and professional and scientific instruments.

According to estimates, industry spent $1.6 billion on energy R&D projects in 1976 with 37 percent of that amount going for fossil fuel R&D, primarily in petroleum. Another 49 percent was directed to nuclear energy. An estimated $663 million was spent on pollution abatement R&D projects in 1976, with 74 percent of that directed towards air pollution programs.

More than two-thirds of total industrial applied research and development expenditures were in six product areas in 1974: communication equipment and electronic components, machinery, aircraft and parts, guided missiles and spacecraft, motor vehicles and other transportation equipment, and chemicals.

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Science and Engineering Personnel

Indicator Highlights

Employment of scientists and engineers in 1974 is estimated at over 1.7 million, about the same number as in 1970; engineers represented two-thirds of this total.

More of the Nation's scientists and engineers were employed in industry than in any other R&D-performing sector—about one million in 1974—and over 80 percent of this group were engineers.

The Federal Government supported less than 25 percent of all industrial scientists and engineers in 1974, down from nearly 30 percent in 1972; industry's life and environmental scientists had the lowest average level of Federal support, at about 5 percent, compared to the highest support (26 percent) for engineers.

Universities and colleges employed about 289,000 scientists and engineers in 1976, about 8,500 or 3 percent more than the number employed in 1975; increases in the number of psychologists and social scientists accounted for 58 percent of this change.

The 160,000 scientists and engineers employed by the Federal Government represented about one of every ten scientists and engineers in 1974. Over the 1964–74 period, employment of scientists and engineers in the Federal Government increased by almost 12 percent, while the employment of scientists and engineers throughout the economy rose by almost 25 percent.

In 1975, approximately 531,000 scientists and engineers (on a full-time-equivalent basis) were engaged in R&D, 9,000 more than the number in 1973, but almost 28,000 fewer than the peak employment level reached in 1969.

About one-third of all scientists and engineers were engaged in R.D activities in 1974. Of these, 68 percent were employed in industry, 13 percent in universities, and 12 percent in the Federal Government.

The proportion of young doctoral faculty in doctoral level science and engineering departments declined from 43 percent in 1968 to 27 percent in 1975; over 70 percent of doctoral faculty in all fields had tenure in 1974.

Women made up 6 percent of all persons employed in science and engineering occupations in 1974, although 9 percent of the total number (employed and unemployed) were women and about 50 percent of all professional and technical workers were women. Those employed were more highly represented among psychologists, computer scientists, and mathematicians than other fields. In the academic sector, women represented 15 percent of all scientists and engineers employed full-time in 1974.

About 4 percent of all scientists and engineers in 1974 were members of racial minority groups. Asians accounted for 1.8 percent, Blacks about 1.5 percent, and other minority groups the remainder.

Between 1972 and 1975, the proportion of National Merit Scholars choosing science as a major declined from 61 to 54 percent, while over the same period the proportion of those planning to major in engineering increased from 9 to 17 percent.

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Public Attitudes Toward Science and Technology

Indicator Highlights

In the public's rankings of ten occupations according to prestige, scientists were second only to physicians in 1972, 1974, and 1976, with engineers in third place. This is in spite of a general decline in the public's regard for the ten occupations from the 1960's to the 1970's and again from 1974 to 1976. The relative standing of scientists has improved since the 1960's.

While the public in general has a high regard for science and scientists, this regard is highest among the relatively affluent and educated and those who have professional or managerial occupations. The least favorable attitudes are held by the poor and uneducated, and those who live and work on farms. These latter groups also respond "no opinion" with high frequency.

About 70 percent of the public believed in 1972 and 1976 that science and technology have changed life for the better, and over half believed that they have done more good than harm. More favorable attitudes on these issues were expressed in 1974 than in either 1972 or 1976.

Improvements in medicine are by far the greatest benefit that the public believes science and technology have produced, followed by space exploration. The most harmful thing is damage to the environment, with the expense and dangers of the space program coming second.

In 1976, 6 percent of the public thought that science and technology have caused most of our problems, 45 perecnt some of our problems, 28 percent few of our problems, and 14 percent none of our problems. In 1972, only 9 percent felt that none of our problems were caused by science and technology. Government decisionmakers were most often cited in 1976 as the group responsible for causing such problems, while business decisionmakers too were often mentioned. Scientists and engineers were very seldom cited, but there was a marginally greater concern about engineers. There was also a marginally greater desire to control technology than science, especially among professionals and the college educated.

The portion of the public that believed that science and technology will eventually solve most problems such as pollution, disease, drug abuse, and crime was 27 percent in 1976. This number had been 30 percent in 1972 and had dropped to 23 percent in 1974.

The two problem areas in which science and technology would be most effective, in the view of the public, are health care and pollution. The two areas in which they would be least effective are thought to be reducing crime, and weather control and prediction.

The areas in which the public would *most* like its tax money spent for science and technology are the same as those in which they are considered potentially most effective. The areas in which the public would *least* like its money spent are space exploration, defense, birth control, and weather control and prediction.

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34. U.S. National Science Foundation. Conference on Technology Transfer and Innovation: Proceedings. Washington, U.S. Government Printing Office, 1967. 126 pp. (NSF 67-5).

Summary of the Proceedings

(By Sumner Myers)*

Under the joint auspices of the National Planning Association and the National Science Foundation, a Conference on Technology Transfer and Innovation was held in the spring of 1966 at the Statler Hilton Hotel in Washington. D.C. The conference grew out of a 3-year NPA study aimed at providing quantitative data about how scientific and technical information is used as a basis for industrial innovation.

One recurring theme of the conference is posed by an early speaker: Is there a technological explosion? Herbert Hollomon, Acting Under Secretary of Commerce, voices the feeling that there is no real technological explosion; that this generation—not unlike its predecessors—may be deluding itself about its own uniqueness. To illustrate his point he cites the productivity index, which shows no radical discontinuity from past trends.

Gerhard Colm, recognizing that the technological explosion is not confirmed by an increasing rate of productivity, offers three reasons why productivity gains caused by technological change may be evolutionary rather than revolutionary: (1) technological advances resulting in new products may not be fully reflected in statistical measures of change; (2) the impact of the explosion may not yet be felt because there is still a substantial time-lag between invention and its diffusion through the economy; and (3) technological change itself sets into motion other changes which reduce the rate of produc-

*Director, R&D Utilization Project, National Planning Association.

tivity gains. Colm points to the shift of high-income consumers from mass-produced staple goods to more labor-intensive services.

"Technological change" or "technological innovation" is often misunderstood to mean primarily highly creative, radically new inventions of great economic importance. In business practice, however, innovation is more often the result of recognizing and adapting an idea than of inventing a brand new one. This was found to be true for two-thirds of the 560 innovations analyzed in the NPA study. The degree of creativity is not necessarily relevant as far as the economy is concerned. It does matter, of course, whether a particular innovation has important economic consequences—like the diesel locomotive—or imperceptible consequences—like a better manifold design.

Industrial innovations result from the utilization of technical information, including research outputs. While most of the innovations NPA studied were not directly based on the output of R&D laboratories, a significant number were. Among railroad innovations, 17 percent were directly based on research outputs; the comparable figure for housing was 27 percent, and for computers, 44 percent. These innovations tended to be more complex and expensive than those based on other kinds of technical information. In any event, before the research outputs and other technical information could be transformed into innovations they had to be somehow transferred to the people who might utilize them.

VERTICAL AND HORIZONTAL TRANSFER

Harvey Brooks, Dean of Harvard School of Engineering, suggests that transfer occurs along two dimensions—vertical and horizontal. In vertical transfer, the general is transformed into the particular; science becomes technology, and technology finally becomes hardware. Horizontal transfer occurs when scientific or technical information generated in one context is "borrowed" by another firm, which usually adapts it *vertically* to meet its own needs. Thus, vertical transfer normally takes place *within* an institution and horizontal transfer takes place *among* institutions.

Horizontal transfer often involves specific hardware or "frozen information." But a good deal of intermediate information is also transferred in the abstract form. In the horizontal transfer process, one institution's input is another institution's output. For example, in the case of the transistor, the research output of Purdue University was horizontally transferred as an input to Bell Telephone Laboratories. Bell, in turn, vertically integrated work done at Purdue University into its own transistor technology; Bell's research output was then horizontally transferred to other firms, this time in a fairly specific form. Finally, the receiving firms further improved this technology, again vertically. And so we have transistors as we know them today.

GOALS AND RELEVANT RESEARCH

The mere existence of a body of research outputs and other technical knowledge is not in itself enough to result in significant industrial innovation. Little information will be transferred, either horizontally or vertically, unless there is a purpose for doing so. Professor John Stedman of the University of Wisconsin Law School emphasizes that the innovative process has no self-starter, nor does it have a built-in guidance system, nor is it inherently powerful enough to overcome all of the barriers—institutional, financial, labor, entrepreneurial, and so on—in its path to success. For innovation to occur somebody must direct the process toward some objective.

In economic terms, technology, applied science, and pure science may be viewed as a spectrum of means to achieve economic ends. Of these, technology exists primarily to serve these ends; its objectives can be set with a fair degree of precision in advance. But how can science, whose outputs are by definition almost unpredictable, be focused on economic purpose?

The findings of Project HINDSIGHT point up the value of science with a purpose. Basic research was found to have made important contributions to weapons development when the work was specifically undertaken to illuminate a problem encountered by a weapons-development mission. Isenson suggests that mission-related science outputs may be more readily used because the scientist in such a project would be in close personal communication with the using engineer. In this connection it is important to note that the success stories involving the use of science research outputs occurred in firms that had achieved effective vertical transfer by closely coupling their science to the rest of the company.

TECHNOLOGICAL GOALS FOR PRIVATE INDUSTRY

Besides the need to set economic goals at the science end of the spectrum, a similar need also exists at the technology end in order to utilize research outputs in meaningful industrial innovations. Fortunately, economic goals for technology are much easier to set. Most people would agree that the goal of technology is to meet needs felt in the marketplace. Granted, the marketplace is always somewhere in the innovating picture, but this statement oversimplifies its role.

In the first place, the market rarely expresses a *felt* need for a product. Rather, choices are made among alternatives offered by producers, and innovations are either accepted or rejected with a sometimes inscrutable logic. Because the market reacts to innovations critically rather than creatively, the risks of innovating for it are inevitably high.

In any event, about half of the innovations studied by NPA occurred in *direct* response to market factors such as changing customer requirements, potential demand, or competitive products. The other half were more immediately stimulated by in-firm requirements: systems changes, quality failures, and the ever-present need for cutting costs.

Entrepreneurial skill is the crucial factor in the innovation process. It takes a special kind of ability to look at a proposal and see its market—where it is, how big it is, and, most importantly, how accessible it is. Many innovations have met every test but the last. The market exists, but the firm cannot reach it. Unfortunately, it is too easy to underestimate both (1) what it will cost to take an idea and translate it into successful business—and (2) how much time it will take. The combined effect can be disastrous. Time is money; a dollar discounted this year is only pennies when a successful innovation at last begins to bring a return to the firm.

SCIENCE, TECHNOLOGY, AND PUBLIC NEEDS

The conference revealed a general sense of dissatisfaction about the innovative process, a dissatisfaction that is both quantitative and qualitative. Some think it is proceeding too slowly; others, too rapidly. There is a growing impatience with the lag between discovery and application. Still others think the output is too wasteful or too irrelevant to society's needs. There is a growing dissatisfaction that technology is failing to solve society's most pressing problems. This note—sounded in the opening remarks of Dr. Leland Haworth, Director of the National Science Foundation—was echoed by other speakers.

Most dissatisfaction with the quality of innovation and the rate of technology utilization boils down to a feeling that—as yet—technology has failed to meet public needs. Spectacular innovations in weapons and space have convinced many people that the outputs of the research establishment offer unique opportunities to meet social goals. Presumably there remains only the problem of deciding what the goals are and who will pay for them. In a pluralistic society this is easy at the general or "motherhood" level but extremely difficult at the specific level—where it counts.

Charpie suggests that a prime social goal is to help business innovate more because industrial innovations create the wealth that makes other goals thinkable. But how shall this be done? Perhaps the best way to help business innovate is to stimulate the economy as a whole. The point was made earlier that about half of the innovations came about in *direct* response to market factors. A rapidly growing economy obviously expands the market for innovations and encourages investment in new ideas. It is less clear what will be accomplished by changing boundary conditions such as patent policy and antitrust regulation.

Given strong enough market incentives and the force of innovative attitudes, boundary conditions may not matter much. Daniel De Simone, Director of the Office of Innovation and Invention at the National Bureau of Standards, sums it up this way: "A sympathetic and encouraging Federal climate is very important, it is not more so, is what goes on in the firm . . . neither the provision of incentives nor the removal of barriers can be an adequate substitute for excellence, boldness, and understanding at the front line of innovation, where the action is."

Stimulating the economy will undoubtedly yield more innovations. But these will be "more of the same" and therefore will still fail to satisfy public needs. This should not be taken as a criticism of innovation in the private sector. Generally, the products of American industry are more than satisfactory for private purposes. The unsatisfactory ones are usually eliminated in the marketplace. Yet, something is missing. There are few industrial innovations developed specifically to fit into systems to perform a function of public interest. For example, component innovations in housing determine the system rather than the other way round. So housing costs more than it should and is not as good as it might be.

The difficulty is compounded when those who now perform essential parts of a function refuse to modify their operations to meet the needs of the whole system. These vested interests constitute by far the most serious institutional barriers to socially important innovations. Ordinarily they can't be ordered to collaborate. Nor will they do so unless they clearly see something in it for them. The problem is how to provide the means for inducing them to integrate voluntarily into a system that performs a socially desirable function.

Money is the force that can align private interests with public purposes. By coupling systems requirements to dollar incentives it will be possible to generate the innovations called for. Michael Michaelis of Arthur D. Little, Inc., describes how this has in fact been done. A group of young architects at Stanford University created a powerful market for innovative school construction systems by aggregating existing but heretofore fragmented markets. They noted that 13 separate school districts in California together needed 22 new schools. In a project sponsored by the Ford Foundation the group of achitects helped the 13 districts to identify their needs and translate these needs into performance specifications. Manufacturers were then asked to propose and bid on subsystems that would meet the performance requirements. Because products as such were not specified, component suppliers were free to come up with new innovations. And because the market opportunity was a fairly substantial one, they found it worthwhile to do so. Indeed, to meet performance requirements of the various subsystems, component suppliers spent over $2,000,000 of their own money on research and development. What's more, much of their research output was later utilized in other construction systems.

THE ACTIVE ROLE OF NEW TECHNICAL INFORMATION

If goals are specified and backed with dollars, the necessary technology will be developed. This is the major pattern of innovation. But it is by no means the only way things happen. There is also a minor but significant pattern in which technology evokes the needs that generate still more technology to get innovation.

The role of technology is not always the passive one of being drawn into the solution of problems. Granting that the market represents the most powerful force in stimulating innovation, we must also recognize that new scientific and technical information often stimulates innovation by defining heretofore undefined needs and problems. A recent New York Times story makes the point. The story describes an exciting trade exhibit where retail merchants were shown the latest automation techniques for billing customers, controlling inventories and so on. The first line of the story quotes one of the merchants: "All of sudden you discover that there are problems you didn't know you had." The story goes on to say that this comment "was typical of the reaction of many other merchants to the presentation of new equipment and services." It illustrates another point as well: before the innovation actually appeared, the market *felt* little and demanded nothing.

We all know from similar personal experiences that new information can stimulate a need that seemingly did not exist before. The question is, how often does this happen? NPA data show that it happens with significant frequency. We found that over one-quarter of the innovations studied were evoked by technical information, including research outputs.

New technical information also lowers barriers to the implementation of old ideas. Ordinarily, few projects that are economically and technically unrealistic are started. Ideas for innovations that are not yet feasible may be shelved. Technology must be used in packages; if all related pieces are not available, the incomplete package may lie dormant for a decade or longer until some key piece of technology completes the package.

As relevant technologies develop, barriers to success are lowered, perhaps to the point where the project becomes economically and technically feasible. When most pieces of technology are available, the few missing pieces will be worked out to satisfy the needs of the now-new market for just those solutions. Sometimes it is not economically feasible for the firm itself to work out every element in the package. In that case the firm has to depend on a horizontal transfer from some other industry which may have developed that element for an entirely different purpose.

This brings us to another reason for tempering the emphasis on well-defined technological objectives. A single-minded preoccupation with clear objectives might foreclose "targets of opportunity." Despite the seeming rationality of working in relevant areas toward specific goals, a certain amount of "thrashing about" is inevitable. Perhaps it is even desirable. As a university president recently said, "In order to discover anything you've got to be working on something." NPA found that one-eighth of all innovations studied began as work on a different, though often related, problem. From the point of view of society (although not necessarily that of the individual firm) it is perhaps better to be working toward poorly defined objectives than not to be working at all. The great value of doing something is that it generates more research outputs, information, and innovative ideas that might be used, perhaps, by somebody else. In short, because the process of innovation reinforces itself, it is important to keep the innovative engine turning.

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35. U.S. National Science Foundation. The Effects of International Technology Transfers on U.S. Economy: Papers and Proceedings of a Colloquium. Washington, U.S. Government Printing Office, 1974. 114 pp. (NSF 74–21).

Introduction and Summary

(By Rolf R. Piekarz)*

I. INTRODUCTION

The papers in this volume stem from interests and concerns expressed by the Science Adviser to the President and by the Executive Office of the President on the status of research and knowledge in international technology transfer. This project reflects the purposes of the National Science Foundation's Office of National R&D Assessment: to supply objective analysis and define options available with regard to enhancing the contribution of science and technology to the nation. The relation between innovation and international technology transfer and the effects of these technology transfers on U.S. economic welfare is one of a number of research topics of concern to the Office's task force on the Scio-Economic Effects of Technological Innovation.[1]

To assess the status of understanding of the effects of international technology transfer, the Office of National R&D Assessment commissioned four experts to review the subject and assess the existing knowledge as it affects policy considerations and research priorities. Professor Robert Stobaugh (Harvard), Professor Richard Caves (Harvard), and Professor Gary Hufbauer (New Mexico)—were asked to address the following questions:

(1) What do we know about the relationship between the following activities:

(a) U.S. technological innovation and U.S. foreign direct investment, licensing, and trade;

(b) U.S. foreign direct investment, and licensing, and the transfer of U.S. technology abroad;

(c) U.S. transfer technology and net changes in U.S. foreign exchange earnings, domestic employment and economic welfare?

(2) How good is the current state of the art in analyzing and measuring these relationships?

(a) What is the adequacy of present research findings?

(b) How good are available analytical models, data, and estimation techniques?

(3) Does our present knowledge suggest consideration of certain policy options?

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*Senior Staff Associate, Office of National R&D Assessment, National Science Foundation.

[1] Details of the National R. & D. Assessment Office research program appear in the Official Program Plan and the Annual Report. These documents may be obtained from the Office.

(4) What must be done to further our knowledge in order to formulate policy options?

Professor Keith Pavitt (Sussex) was asked to apply his knowledge of post World War II science and technology experience and policies of the OECD nations to some issues in the current U.S. public policy debate on U.S. international technology transfer and the relative decline in the U.S. technology position.

The paper by Professor Stobaugh is *A Summary Assessment of the Research Findings on U.S. International Transactions Involving Technology Transfers.* Professor Stobaugh sketches the research results and the gaps in analyzing and measuring the relationships between U.S. international technology transfers and various economic and policy variables. The author concentrates on two questions: What do we know about the relationships between U.S. technological innovation, technology transfer from and to the United States, foreign direct investment, foreign licensing, foreign trade, and net changes in U.S. foreign exchange earnings, employment, and economic welfare? What research must be done to further our knowledge in order to formulate and assess policy options?

Professor Caves' paper, *Effect of International Technology Transfers on the U.S. Economy*, focuses on the adequacy of present research findings, analytical models, and data for addressing public policy concerns about international technology transfer. The paper divides into two parts. The first assesses the scope and adequacy of the evidence on technology transfer entailed in various U.S. international transactions and the consequences which result. The second part outlines some high priority research and examines the adequacy of available models, data, and techniques.

Professor Hufbauer, in his paper, *Technology Transfers and the American Economy*, concentrates on enumerating and explaining the conditions which should be taken into account in framing and examining policy options with regard to international technology transfer. The first half of the paper outlines what we know about industry characteristics and company choices with regard to the magnitude, form, and determinants of international technology transfers. The author then describes and assesses the national economic welfare considerations which have been applied in public policy discussions. Professor Hufbauer concludes the paper with some recommended research topics arising from his discussion.

The contribution by Professor Pavitt is *"International" Technology and the U.S. Economy: Is there a Problem?* The author addresses some policy issues and possible future trends in international transactions involving technology arising from the experience of industrial nations during the past 20 years with technological innovation and technology exchange. Professor Pavitt first traces out the changing patterns of technological development and its transfer in and between Europe and the United States during this century, especially since World War II. He then discusses the experience of Western Europe with government funding of R&D in industry, the changing patterns of industrial R&D in the OECD countries, and the way in which these countries have exploited their technological capabilities in international markets. These findings then are used to make some judgments about U.S. policy problems and options, and some possible trends.

The papers are necessarily limited by the scope described, as well as by constraints which each contributor faced in terms of his own time and the short deadline placed upon him. NSF is indebted to the contributors for producing this material under such circumstances. We ask that the reader view the output with an understanding of what can be accomplished in a brief paper even under lesser time constraints. As one of the authors pointed out: "Any attempt to evaluate fully the relation between international transfers of technology and the United States economy—even as a survey of the state of information—would require its author to command an enormous knowledge of the determinants and consequences of research in American industry (including the domestic invention-innovation-diffusion cycle), U.S. international trade, foreign direct investment (and technology transfers within the multinational firm), international licensing and the market for proprietary technology, and the ingestion and modification of innovations by industry abroad." (Caves).

II. CONCLUSIONS

This section presents for each question the overriding conclusions stemming from the papers. The next section, "Selected Quotes," provides for each question quotes from the papers which support and extend these conclusions.

(1a) What do we know about the relationship between U.S. technological innovation and U.S. foreign direct investment, licensing, and trade?

We know that U.S. industries spending relatively high amounts on R&D are the leading industries in manufactured exports, foreign direct investment, and licensing. The limited extant research at the level of the firm has not established a relationship between research intensiveness and the share of exports in domestic sales, the ratio of foreign to domestic production, or the share of earnings from foreign licensing. We lack information about the impact of the type or recency of innovations on exports, foreign direct investment, and licensing. Also, we do not know the influence of exports, foreign direct investment, and licensing on the rate or direction of R&D and technological innovation by U.S. firms.

(1b) What do we know about U.S. foreign direct investment and licensing and the transfer of U.S. technology abroad?

We know that U.S. foreign direct investment and licensing are channels by which foreign countries obtain technological knowledge. We do not know the mechanics, magnitude, or rate at which this technology diffuses abroad. Also, there is no information about the complementarity and substitutability among exports, foreign direct investment, and licensing as channels for technology transfer.

(1c) What do we know about the relationship between U.S. technology transfer abroad and net changes in U.S. foreign exchange earnings, domestic employment, and economic welfare?

(2) How good is the current state of the art in analyzing and measuring these relationships?

(a) What is the adequacy of present research findings?

(b) How good are available analytical models, data, and estimation techniques?

Existing empirical research findings permit some judgments about the selection by a firm of the channels and timing of the diffusion of its specialized knowledge abroad. Available analytic models permit us to determine the variables for framing and studying specific questions concerning the above relationships. Much existing empirical research suffers from the failure to utilize properly the known models. Admittedly, application of such models entails substantial difficulties in estimation. One major analytical gap does exist. This is the lack of a yardstick for measuring the output from R&D and technological innovation and the amount of technology transferred.

(3) Does our present knowledge suggest consideration of certain policy options?

Except for national security purposes, the U.S. Government should not at this time consider actions to discourage or restrict international transactions involving technology transfers. We lack evidence whether, where, or when such transactions harm U.S. welfare. If loss to U.S. welfare were established, there are some options the government may want to consider and some which are likely to prove ineffective.

(4) What must be done to further our knowledge in order to improve our capability to formulate policy options?

The contributors generally agree that the subject of the causes, characteristics and consequences of international technology transfer should be given a great deal more research attention. A quote from one of the contributors sums up this conclusion as follows: "In the quest for this knowledge (of the impact of technology transfers on the U.S. economy), our position is similar to that of a diner just starting to eat an artichoke. We have tasted a leaf or two but most of the discovery is ahead of us. Innumerable leaves remain to be peeled off before the heart is reached." (Stobaugh)

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36. U.S. National Science Foundation. Preliminary Papers for a Colloquium on the Relationships Between R. & D. and Economic Growth/Productivity. Washington, 1977, various pagings.

INTRODUCTION AND SUMMARY

(By Rolf R. Piekarz)

Public officials, the R&D community, and economic analysts have increasingly focused their attention on the relationship between research and development and economic growth/productivity. Six years ago, the National Science Foundation sponsored a colloquim to assess the state of knowledge at that time about the economic aspects of R&D.[1] In the intervening years Congress has sponsored a number of studies and held hearings, Federal departments and agencies have issued reports and conducted assessments, and the National Science Foundation has sponsored research on this topic. As the papers in this volume attest, these efforts have added to our knowledge about the relationship between R&D and economic growth/productivity, about the possibilities for government action, and about lines of research for improving our understanding.

II. CONTENTS

The first paper, by Professor Mansfield, is, "Research and Development, Productivity Change, and Public Policy." It presents a summary of findings of recent research on the relationship between R&D and productivity change and on the measurement of social and private returns from individual technological innovations. It then examines briefly the analytic and empirical experience with Federal policies to stimulate R&D for economic purposes and indicates what this experience suggests for guidelines to Federal action. The paper concludes with some topics for further research.

Professor Nadiri covers three topics in his paper, "The Contribution of Research and Development to Economic Growth." He surveys the recent research on the measuring of the contribution of R&D to productivity improvement and to private and social returns. Second, the paper examines some of the work on the determinants of R&D and technological innovations. Third, there is a brief review of the problem of measurement. The paper concludes with a list of topics for research.

Dr. Terleckyj focuses his paper on, "Recent Findings Regarding the Contribution of Industrial R&D to Economic Growth." His discussion of recent research findings about the effects of R&D on economic growth emphasizes attempts to measure direct and indirect effects of R&D and the contribution of government financed R&D. After a brief summary of some recent research on the process of innovation, the paper summarizes Dr. Terleckyj's views of the policy significance of the findings of the available research information. A few questions for additional research conclude the paper.

Dr. Eads concentrates his review on the theme, "Achieving 'Appropriate' Levels of Investment in Technological Change: What Have We Learned?" First, he sketches what recent research tells us about the importance of different information for understanding the relationship between R&D and productivity. Second, he indicates what recent research tells us about the perspective for addressing questions about underinvestment. Third, there is a summary of what recent government initiatives and research have taught us about government efforts to stimulate industrial R&D. He concludes with some suggestions for research.

Professor Kendrick focuses his paper on, "policies to Promote R&D and Productivity Growth." His discussion on policies concentrates on measures to stimulate long term investment, of which R&D is one component, and on measures directed to encouraging R&D.

III. CONCLUSIONS OF THE 1971 COLLOQUIUM

A summary statement of the conclusions of the papers from the 1971 colloquium would help to put the findings and conclusions of the papers of this colloquium in context. The four questions posed to the authors and the overriding conclusions for each question were as follows:

1. "What do we know about the relationship between R&D and economic growth/productivity?"

"Although what we know about the relationship between R&D and economic growth/productivity is limited, all available evidence indicates that R&D is an important contributor to measure this relationship (at the level of the firm, the industry, and the whole economy) points in a single direction—the contribution of R&D to economic growth/productivity is positive, significant and high."

2. "How good is the current state-of-the-art on the subject?"

"While there are differences concerning the adequacy of present research findings, these seem to affect the degree of confidence the contributors place on

[1] National Science Foundation. "Research and Development and Economic Growth/Productivity, Papers and Proceedings of a Colloquium" (Washington, D.C.: Government Printing Office, 1972).

the estimates rather than the direction and rough magnitude of the estimates. The current state-of-the-art is not strong enough to permit definitive estimates of the contribution of R&D to economic/productivity and results are subject to considerable error. Nonetheless, the results cited in the papers lead each of the authors to the conclusions stated above."

3. "Are we in a position to make any judgments concerning whether the United States in under- or overinvesting in R&D purely from the economic growth/ productivity aspect?"

"The authors agree that, based upon the evidence, good judgment would lead to the conclusion that the United States is probably underinvesting in civilian sector R&D from a purely economic growth/productivity point of view.

However, nothing can be said, based upon this conclusion as to where particular R&D investments should be made. What this judgment means is good reason to expect that a well diversified incremental R&D investment will result in high payoffs similar in magnitude to those of the past."

"What might be the next logical steps in furthering our knowledge of the relationship so as to reduce the area of judgment?"

"All contributors agree that many of the limitations discussed in the papers are a result of the relatively small amount of research attention given to this subject. No one is satisfied with the current state-of-the-art and priorities in this respect are suggested in the papers, as follows: Mansfield: 21–36; Fellner: 37–46, Griliches: 47–51."

IV. FINDINGS AND CONCLUSIONS

This section presents a summary of the five papers organized around the questions listed in the section of Scope and Purpose. The summary consists of two parts: first, it presents the central conclusion extracted from the papers with respect to each question; second, it presents the findings and observations from individual papers which support and extend the major points made in the conclusion.

(1) What additional information has been developed since 1970 about the contributions of R&D to economic growth/productivity and about the adequacy of R&D investments for economic purposes?

a. Contribution to economic growth/productivity

Recent research has reinforced the earlier findings that the contribution of R&D to economic growth/productivity is high. In addition, the research on industrial R&D suggests the contributions differ by industry and by source of funding (e.g., government versus private). Also, the research shows that the economic benefits to society exceed substantially the returns received by the firms producing the R&D outputs. Unfortunately, little progress has been made in solving basic measurement and modeling problems, which were cited in the 1971 colloquiums.

b. Adequacy of R&D investments for economic purposes

As in the 1971 colloquium, the authors of the present papers state as their impression that there may be some underinvestment in R&D on an aggregate basis. However, the current state of knowledge suggests that for public policy purposes inadequacies in R&D investment must be considered on a case by case basis.

(2) What conclusions do the research and experience since 1970 suggest about options for government actions to influence the rate and effectiveness of R&D?

Recent research and experience teach us that indiscriminate government intervention is likely to be ineffectual in promoting R&D for economic purposes and may be detrimental to the economic use of scarce resources. Aside from macroeconomic stimulus, designing constructive interventions is more difficult than generally believed. Instruments must be applied selectively to take account of specific outcomes described or market conditions.

3. What are topics for major incremental gains in knowledge?

One of the authors may have been speaking for all when he concluded, '. . . [W]e have not 'solved' many of the 'problems' that the 1971 colloquium highlighted, but we at least now know much better what the real issues are and how they ought to be addressed (Eads, page D–18). Each paper suggests a few topics for research. Expectations for answers should be realistic, since as another author concludes, ". . ., I should stress once more that the problems of modeling, measurement, and interpretation in this area are exceedingly complex, and that economists are unlikely to be able to provide more than partial answers to important questions facing policy makers." (Mansfield, page A–16).

37. U.S. National Science Foundation. Research and Development and Economic Growth/Productivity: Papers and Proceedings of a Colloquium. Washington, U.S. Government Printing Office, 1972, 84 pp. (NSF 72-303).

SUMMARY OF THE PAPERS

(By Leonard L. Lederman)*

The following summary of the four papers is organized around the questions listed in the section on *Scope and Purpose.* The summary consists of first, a brief statement representing the overriding conclusion expressed in the papers with respect to each question and then material drawn from the papers which provide support for and extension of the major points made in the conclusion as well as the range of views held.

(a) *What do we know about the relationship between R&D and economic growth/productivity?*

Although what we know about the relationship between R&D and economic growth/productivity is limited, all available evidence indicates that R&D is an important contributor to economic growth and productivity. Research to date seeking to measure this relationship (at the level of the firm, the industry, and the whole economy) points in a single direction—the contribution of R&D to economic growth/productivity is positive, significant and high.

* * * * * * *

Various studies have attempted to establish different things. First they have examined the correlation between R&D time series (or R&D aggregated over a number of years) and time series of productivity increase (or productivity increase over a number of years) . . . A positive and significant correlation has usually been found . . . Some have calculated rates of return and marginal rates of return on investment in R&D. These have usually been quite high, but they vary widely. (Stewart, page 12)

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. . . it is celar that the current state-of-the-art in this area is not strong enough to permit definitive estimation of these relationships. Nonetheless, although the results are subject to considerable error, they establish certain broad conclusions. In particular, existing econometric studies do provide reasonably persuasive evidence that R&D has a significant effect on the rate of productivity increase in the industries and time periods that have been studied. (Mansfield, page 25)

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. . . these studies rely on the results of several econometric investigations that indicate that, for the industries and fields under investigation, the marginal rate of return from an investment in research and development has been very high. (Mansfield, page 28)

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All reasonable ways of looking at the matter lead to the conclusion that the rates of return are very high as compared to usual estimates of rates of return on capital formation.

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Investment in research, both private and public, has clearly been one of the major sources of growth in output per man in this century. It has been a good investment both in the sense that it yielded a positive rate of return, and in the sense that this rate of return has been as good and often better than the rate of return on other private and public investments. The evidence for these statements is scattered: much of it is secondhand: but it is still quite strong. (Griliches, page 47)

The actual estimates of contribution and rate of return can only be understood in terms of what level is under study (e.g., individual innovations, the firm, the industry, the economy as a whole), what is being measured (e.g., contribution to economic growth, to national productivity, to the productivity of an individual industry or firm), and what methodology is employed in making the measurement (e.g., direct econometric measures, aggregate residual measures). Accordingly, the reader must read the full context in which such estimates are provided. The following are the major estimates provided with a reference to the text which is necessary for proper understanding.

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*Deputy Head, Office of Economic and Manpower Studies, National Science Foundation.

Turning to manufacturing, Mansfield and Minasian estimated the marginal rate of return from R&D in the chemical and petroleum industries. Mansfield's results indicated that the marginal rate or return was about 40 percent or more in the petroleum industry, and about 30 percent in the chemical industry if technological change was capital embodied (but much less if it was disembodied). Minasian's results indicated about a 50-perecnt marginal rate of return on investment in R&D in the chemical industry. In addition, Mansfield provided some evidence that the marginal rate of return seemed relatively high (15 percent or more) in the food, apparel, and furniture industries. (Mansfield, page 28)

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As explained on pp. 19–20 of my article in the March 1970, issue of the AER (AEA presidential address), the average rates of return calculated in the manner described above fall in the range between 31 percent and 55 percent for 1966. (Fellner, page 42)

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This evidence is of three kinds: individual invention returns calculations, industry studies, and aggregate residual attribution calculations . . . The internal rates of return implied by these estimates of individual inventions are quite high (10 to 50 percent per annum), even though they are usually based on conservative assumption . . .

While each of these (industry) studies is subject to a variety of separate reservations, together they all point to relatively high (30–50 percent) rates of return on average to both public and private investments in research. (Griliches, page 47)

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Thus, without knowing definitively what is the relation between R&D and productivity change, we can safely conclude that our existing measures of productivity change understate the contribution of R&D. (Stewart, page 18)

(b) *How good is the current state-of-the-art on the subject?*

While there are differences concerning the adequacy of present research findings, these seem to affect the degree of confidence the contributors place on the estimates rather than the direction and rough magnitude of the estimates. The current state-of-the-art is not strong enough to permit definitive estimates of the contribution of R&D to economic growth/productivity and results are subject to considerable error. Nonetheless, the results cited in the papers lead each of the authors to the conclusions stated above.

By the standards of the scientific community one cannot be strongly assertive above some of the analytical results to be presented, in particular about the underallocation of resources to the progress-generating activities. The conclusions will be formulated accordingly. However, in most practical decision problems it is necessary to rely on somewhat inconclusive evidence, and the indications derived from the materials here surveyed are strong enough to be considered analogous to indications on the basis of which action is indeed taken in many real-life situations. (Fellner, page 37)

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In conclusion, technological change has certainly contributed in a very important way to economic growth in the United States. Although existing studies have not been able to estimate this contribution with great accuracy, they have certainly indicated that this contribution has been large. Moreover, although econometric studies of the relationship between R&D and productivity increase have been subject to many limitations, they provide reasonably persuasive evidence that R&D has an important effect on productivity increase in the industries and time periods that have been studied. (Mansfield, page 33)

The research results reported above are subject to a number of important limitations of at least two major kinds:

1. Limitations concerning the specific findings and specific methodologies employed. Examples include: the difficulty of going from contributions of technological change to the specific contribution of R&D; the problem of estimating the time lag between R&D investment and economic impact; difficulty in deflating R&D expenditures for price changes. These are best considered simultaneously with the findings, and the references provided above (a) should enable the reader to do this.

2. Limitations that are more general and affect much, if not all, of the work to date. Examples include: difficulty of isolating any one factor (i.e., R&D) from the complex interaction of factors contributing to economic growth/productivity; measurements that inadequately reflect quality changes; positive correlations that do not necessarily imply causation. The following excerpts from the papers summarize this second kind of limitation.

The state-of-the-art is least satisfactory in measuring the relationship between R&D and productivity gain. This is true for two reasons: 1. R&D (or economic resources devoted to the advancement of productivity-relevant technological knowledge) is not the only source of productivity growth; and 2. R&D and other sources of growth are interdependent.

Other factors in productivity gain which have been stressed include organizational and managerial progress and economies of scale and urbanization. But their contribution is no more readily quantified than that of R&D. The major difficulty seems to be interdependence. (Stewart, page 17)

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First, the measured rates of growth of output on which these estimates are based suffer from a very important defect, particularly for present purposes, because, to a large extent, they fail to give proper credit and weight to improvements in the quality of goods and services produced, and these improvements are an important result of research and development. For example, the growth rate would have been the same whether antibiotics were developed or not, or whether we devoted the resources used to reach the moon to public works. In general, only those changes in technology that reduce the costs of end products already in existence have an effect on measured economic growth. Unfortunately, the measured growth of national income fails to register or indicate the effects on consumer welfare of the increased spectrum of choice arising from the introduction of new products. (Mansfield, page 22)

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There are difficulties caused by the fact that much of the Nation's R&D is devoted to defense and space purposes. For example, some observers note the tremendous increase in R&D expenditures in the postwar period and conclude that, because productivity has not risen much faster in the United States than before the war, the effect of R&D on economic growth must be very small. What these observers forget is that the bulk of the Nation's R&D expenditures has been devoted to defense and space objectives and that the contribution of such expenditures to economic growth may have been limited.

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Even if one were sure that the R&D figures were reliable, there would still be the possibility of spurious correlation. Firms and industries that spend relatively large amounts on research and development may tend to have managements that are relatively progressive and forward-looking. To what extent is the observed relationship between R&D and productivity increase due to this factor rather than to R&D? Obviously, this is difficult to answer since the quality of management is very difficult to measure. Nonetheless, most investigators seem to feel that only a small part of the observed relationship is due to spurious correlation of this sort. (Mansfield, page 24)

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A large percentage of the R&D carried out by many industries is directed at productivity increase in other industries. Consequently, relationships between R&D in an industry or firm and productivity increase in the same industry or firm catch only part of the effects of R&D. . . . Also, the estimates that are obtained depend on the extent of the lag between the time when R&D is carried out and the time when the effects of R&D show up in productivity indexes. Clearly, this lag is often substantial. Unfortunately, the models on which these estimates are based often make very crude assumptions concerning the length of the lag. (Mansfield, page 24)

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Studies of national productivity vary in completeness. Some limit themselves to the private nonfarm economy; others cover the total private market economy; others include government as well. The reason for excluding government in some studies is the lack of any measure of government output, and therefore of productivity change. As a result, studies including government count it at cost, probably understating productivity gain for the economy as a whole. Some studies assume a productivity gain in government equal to that in the service sectors (not all of which have measurable output and therefore measured productivity change). (Stewart, page 15)

Technological progress has harmful as well as beneficial byproducts and the harmful byproducts also expres themselves largely in nonmarket results which may be regarded as negative nonmarket values. These negative items evade rough numerical appraisal by rule of thumb, and this is partly because it is not clear to what extent they are associated with technological progress in its various phases. (Fellner, page 41)

The rate of utilization of plant and equipment varies substantially as a percentage of capacity. This results in cyclical variation in capital (and total factor) productivity. But if there is a long-run trend toward fuller utilization of capacity, total factor productivity increase will be slightly higher than it would have been for a given level of utilization. (Stewart, page 15)

(c) *Are we in a position to make any judgments concerning whether the United States is under- or overinvesting in R&D purely from the economic growth/productivity aspect?*

The authors agree that, based upon the evidence, good judgment would lead to the conclusion that the United States is probably underinvesting in civilian sector R&D from a purely economic growth/productivity point of view. However, nothing can be said, based upon this conclusion, as to where particular R&D investments should be made. What this judgment means is that there is good reason to expect that a well diversified incremental R&D investment will result in high payoffs similar in magnitude to those of the past.

Turning to the adequacy of the Nation's investment in research and development, there is too little evidence to support a very confident judgment as to whether or not we are underinvesting in certain types of research and development. However, practically all of the studies addressed to this question seem to conclude, with varying degrees of confidence, that we may be underinvesting in particular types of R&D in the civilian sector of the economy, and the estimated marginal rates of return from certain types of civilian research and development seem very high. (Mansfield, page 33)

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Reasonable estimates lead to the conclusion that the returns are very high in the American economy. A good case can therefore be made for increasing the weight of progress-generating inputs in the economy as a whole. Of late we have been moving more in the opposite direction. (Fellner, page 37)

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Most economists, if queried, would assert that there is underinvestment in research by private firms because much of its product is not capturable (appropriable) by the private firm. (Griliches, page 48)

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The first proposition is that, because the results of research are often of little direct value to the sponsoring firm but of great value to other firms, there is good reason to believe that, left to its own devices, the market would allocate too few resources to R&D—and that the shortfall would be particularly great at the more basic end of the R&D spectrum. . .

The second proposition is that, because research and development is risky for the individual firm, there is good reason to believe that the market, left to its own devices, would allocate too few resources to R&D. Of course, the risk to the individual investor in R&D is greater than the risk to society, since the results of the R&D may be useful to someone else, not to himself, and he may be unable to obtain from the user the full value of the information. Because the economic system has limited and imperfect ways to shift risks, these would be an underinvestment in R&D. For this reason too, one would expect underinvestment to be greatest at the more basic end of the R&D spectrum. (Mansfield, pages 25)

(d) *What might be the next logical steps in furthering our knowledge of the relationship so as to reduce the area of judgment?*

All contributors agree that many of the limitations discussed in the papers are a result of the relatively small amount of research attention given to this subject. No one is satisfied with the current state-of-the-art and priorities in this respect are suggested in the papers, as follows: Mansfield: 21–36; Fellner: 37–46; and Griliches: 47–51.

38. U.S. National Science Foundation. Science and Technology: Annual Report to the Congress. Washington, U.S. Government Printing Office, 1978, 137 pp.

SUMMARY

This first annual science and technology report discusses some of the key developments and public policy issues concerning the funding and performance of U.S. science and technology. Chapter 1 provides a strategic overview of current issues and policy questions. The Federal S&T policy and R&D budget choices are discussed in Chapters 2 and 3. The theoretical and empirical bases for government R&D policy are set out in Chapters 4 and 5. These chapters also discuss the policy tradeoffs between direct and indirect government action to influence the R&D "market". Finally, Chapters 6 and 7 discuss issues connected with maintaining a sound R&D capability in industry and universities.

Highlights of the findings and policy implications from each of these sections are presented below.

FEDERAL FUNDING OF RESEARCH AND DEVELOPMENT (CHAPTERS 2 AND 3)

As the supplier of about one-half of the Nation's R&D expenditures, the Federal Government has a strong influence on priorities and developments in S&T. Chapter 2 looks at the 10-year national and Federal funding patterns for R&D as background for a more detailed examination of the current fiscal year R&D budget decisions. Some ofthe more significant trends recorded are:

Total national R&D expenditures in FY 1979 will be double (in current dollars) the amount spent 10 years earlier.

Between 1969 and 1975, Federal R&D funding declined 17 percent in constant dollars but since his climbed 14 percent.

Federal R&D priorities have shifted toward civilian-oriented programs and away from defense and space. However, this trend has reversed in the last two years.

Since 1976 Federal basic research obligations have increased by 25 percent in constant dollars.

R&D AND ECONOMIC PROGRESS (CHAPTER 4)

Economists have in recent years turned their attention increasingly to the relation of R&D to economic progress as measured by such indicators as gross national product (GNP) and productivity. Although there are many reservations about methods and data, economists have agreed on these points.

1. R&D is an important contributor to economic growth and productivity, whether measured at the level of the firm, an industry or the whole economy.
2. R&D investments by industry generate relatively high rates of return compared to estimates of return on other types of investments.
3. The U.S. is probably underinvesting in the civilian R&D sector from a purely economic growth/productivity point of view.
4. The market mechanism by itself is likely to lead to an underinvestment in research and development from society's point of view.

The last two points are usually explained by the lack of appropriability of basic research results on one hand, and on the other, high risks and high costs associated with some socially desirable demonstration and development projects. These risks and costs are sometimes viewed as exceeding the capabilities of the private sector, despite the potential of high overall benefits to society.

It is postulated that the existence of these conditions provides a rationale for action by government. But there is no consensus on the proper type and amount of government action. The approach taken to date has been to increase government funding of basic research and to initiate limited experiments to alter market incentives. However, a major Administration policy review is underway in the area of industrial innovation that will take stock of these approaches and assess the need for enhanced incentives. For example, it has been suggested that Federal tax policies should favor R&D expenditures, and that regulations on patents and health, safety and environment standards might be changed to increase innovation. There is growing concern over diversion of industrial R&D from creating new and improved products, processes, and services toward satisfaction of regulatory constraints. While no specific policy responses are indicated in this report, the studies reviewed in Chapter 4 suggest several criteria and guidelines for public policy:

1. Federal S&T policy and practice should be consistent with economic and social policy.

2. Federal policy and practice should be consistent over time and should avoid constant change and uncertainties, which discourage private investment.

3. Whenever possible, Federal policy and practice should reinforce and help perfect private market forces rather than substitute for them. There is growing evidence that governments tend to carry substitution activities too far or remain involved too long.

COMPARATIVE PERFORMANCE OF U.S. TECHNOLOGY (CHAPTER 5)

Aggregate data on R&D inputs of several countries show a rise in rates of technological investment above that of the U.S. for the period 1963–1977. These data include R&D as a share of GNP and the ratio of R&D scientists and engineers to total labor force. The relative decline of the U.S. position measured by these ratios can be attributed partially to the reduction in U.S. Government R&D funds since 1969 for national defense and space. While industrial R&D funding in West Germany and Japan has narrowed U.S. leadership, a closer look at cross-national data on R&D spending shows that the R&D intensity of U.S. manufacturing industries (the ratio of R&D spending to value added in manufacturing) compared favorably with all industrial nations through 1973 and that the United States had, in general, maintained its relative position.

Data on technological output (e.g., patenting, licensing, and international earnings from R&D intensive activities) are inadequate to enable us to make unqualified claims regarding U.S. technological capabilities. Based on the data we do have, it seems fair to say that there has been little or no erosion in U.S. technological capabilities. Neither the available economic nor technical indicators provide hard evidence of an eroding U.S. technical position which can be tied to negative economic consequences. The United States continues to gain strength in the commercial exploitation of technology. However, in specific technical fields, some foreign competitors likely will overtake the United States and some will fall farther behind. Overall, the United States appears to be maintaining its scientific and technological alvantage. Nevertheless it would be advisable to continue monitoring the trends. Given continuing evidence of high private and social returns, it would appear prudent for the United States to sustain, or, if possible, to increase current and projected investments in R&D.

BASIC RESEARCH IN INDUSTRY (CHAPTER 6)

The Administration has indicated its concern over the continued health of innovation in the industrial sector by launching a major policy review. One cause of the concern is industry's alleged shift away from longer-term research (basic and applied) to shorter-term development work and the implication that this might have adverse effects on U.S. economic well-being.

Over the 1960–1977 period there has been indeed, a gradual shift in industry's allocations of R&D resources away from basic and applied research to development. At present there is no general agreement as to whether this trend will have an adverse effect on the U.S. economy. One reason for this is the extreme difficulty in isolating and measuring the contribution of basic research to economic growth and industrial development relative to the contribution of other R&D categories.

One suggested implication of the decline in industrial basic research is that knowledge transfer or dissemination mechanisms will gain importance. This is because industry increasingly is relying on outside contracts for basic research. Judging from its behavior, industry apparently believes that effective transfer is possible and that researchers in other sectors are prepared to deal with industry's interests in near term payoff.

A greater role for industry in basic research may be desired. Industry funding of more basic research may improve the process of transforming research findings into improved productivity and output growth, and might expand the research base of the economy. Encouraging research in institutions with a substantial ability to cost share may enable the government to increase the leverage of a given Federal research budget.

Currently, there is very little quantitative evidence on the cost and effectiveness of alternative incentives for encouraging R & D and innovative activity.

Even less is known about the impact of such policies on basic research. New information on these issues will appear during the Administration's major policy review discussed in Chapter 1.

SOME ISSUES IN SUPPORT OF ACADEMIC SCIENCE (CHAPTER 7)

Universities and colleges perform over one-half of all basic research in the Nation and receive over half the Federal Government's funds for basic research. While Federal-university ties are strong, a number of trends have developed that cause concern, including:

University perceptions of pressure to conduct more applied research;

Differential rates in Federal funding by field of science which influence the supply of researchers;

Declining research opportunities for new scientists; and

Deteriorating instrumentation and other supporting resources for academic research.

Considerable concern is being expressed today that failure to reverse these patterns could cause a serious erosion of the Nation's academic research base.

CHAPTER 1. STRATEGIC OVERVIEW

Americans can be justly proud of their role in the advancement of science. For example, U.S. scientists author almost 40 percent of the world's scientific and technical publications. There has been some worry, though, that the continued preeminence of American science is threatened. In the late 1960's and early 1970's there was a decline in real dollars in the level of support for U.S. basic research. It was believed that this trend would lead to reduced scientific productivity in the future. The growth in basic research funding in the last few years—described later in this report—should help maintain our scientific capability.

Although those involved in basic research pursue their work to better understand nature, scientific achievement, in many cases, becomes linked to technological innovation and economic development. In a simple model of economic change, the sequence proceeds from basic research to applied R&D, then to technological innovation, and finally to economic growth and the increase in social welfare. Of course, our actual system is much more complex and subtle than this model implies. Often applied research or even development will open new avenues of inquiry for basic science, and all basic research cannot be expected to lead directly to technological advance. Nonetheless, a positive relation exists between R&D and increased social and economic welfare.

In discussing R&D policy, there is one overriding issue. We need a better definition of, and greater consensus on, our long-term goals in R&D. Indeed, this need is one that we periodically recognize as important. The latest recognition can be found in Public Law 94–282, which created the Office of Science and Technology Policy. Title I of this Act finds that "the many large and complex scientific and technological factors which increasingly influence the course of national and international events require appropriate provision, involving long-range, inclusive planning as well as more immediate program development..." The Act also speaks of Federal funding for S&T as representing "an investment in the future" and refers to the need for "policy planning" and the "maintenance of a solid base for science and technology..."

Viewing R&D as an investment choice implies recognizing that continuity and long-range support are essential to the entire scientific and technological enterprise. Although R&D should neither be disengaged from the Federal budget cycle nor be locked into inflexible plans, the design and emphasis of our R&D programs should not be rehashed and redirected in each budget cycle. A longer-term approach would allow sufficient continuity so that programs could build momentum. Moreover, the establishment of long-range goals would provide benchmarks for measuring our progress. Perhaps more important, a multi-year strategy of planning and support would provide needed encouragement to our scientists and technicians and their support staffs. If we are to attract and hold the best people in any discipline—and expect them to produce their best—we have to provide continuity and stability.

A related and recurring issue is the need for clearer understanding on how the burdens and responsibilities for R&D funding should be shared. For example, although our long-range goals may provide guidance in choosing areas for emphasis in development, there remains the problem of defining the appropriate role for industry. The approach in some costly, high technology fields, such as the generation of nuclear power, has been for the Federal Government to carry a technology well into the demonstration stage before turning it over to the private sector.

Many believe that by providing incentives, or reducing risks and uncertainties, industry could and should be brought into the development phase much earlier. It is argued that industry can be far more effective in development than the government because of its greater sensitivity to market forces. Moreover, the costs of development might well be less if industry bears part of the burden. The problem, of course, is designing an appropriate relationship between government and industry in each particular situation. The approach must be tailored to the structure of the industry, the state of the technology, and the market for the innovation, as well as the societal need for the technology and its accelerated development. Continued analysis is both important and necessary. During the next year, the Administration will give high priority to such analysis. Chapters 4–7 of this report are designed to provide some of the intellectual foundations for that analysis.

Another strategic issue that warrants continued examination is enhancing the linkage between the performers of research, in particular between industry and universities. As the data discussed later in this report indicates, most of the basic research in the U.S. is performed in a university setting, whereas the development effort is largely an industrial activity. If the desired flow of information is to occur, as well as the highly valuable cross-fertilization, it is important that industry-university relationships be strengthened and that technology transfer mechanisms be improved. NSF has made and is making some exploratory efforts in this area, as has the Department of Defense's Advance Research Project Agency (ARPA). Some states are having success in bringing their universities and industry closer together. Nonetheless, continued surveillance is warranted to assure that the organizational structure of our research enterprise does not inhibit the flow of scientific and technical information.

The distribution of scientists and engineers is another important issue. It has always been difficult to regulate the flow of men and women into the various science and engineering fields, to provide opportunity for our trained talent, and to match that talent to the changing needs of government, industry, and academia. We are now in a particularly trying period because our changing demography is leading to declining enrollments in universities. In the U.S., teaching and research have in the past always been considered joint products of the higher education system. But this means the supply of researchers is heavily dependent on our educational requirements. Given the prospect of decreasing enrollments, many recently trained scientists and engineers cannot find work in the academic sector. Since these individuals represent a highly productive resource, we need to re-examine programs and policies concerning these new investigators. Better mechanisms must be developed for anticipating the needs of various fields and directing our talent to them.

The adequacy of our facilities and equipment is hopefully a short-range issue. The success of our R&D effort has become increasingly tied to the use of larger, more sophisticated equipment and facilities. Today's work demands both elaborate equipment, and complex and sensitive instrumentation. Moreover, this often fragile gear must be housed, maintained, and serviced properly. Not surprisingly, the cost of such equipment has grown rapidly. Indeed, inflation has struck science—price increases of some equipment seem to take quantum leaps. Concurrently, our budget allocations have not kept pace with the cost increases and there is widespread concern that we have an inventory of aging equipment that may need replacement. More precise information is required to pinpoint the age, composition, and distribution of this equipment. In some fields, it may be possible to alleviate the problem by requiring more sharing of expensive new equipment and facilities than has been typical in the past. Some experiments in equipment sharing are being conducted by NSF. Other agencies may have to increase their efforts as well.

In sum, while our Federal R&D program is a strong one, many policy issues concerning our national S&T activities need to be addressed. Fair and cost-effective solutions are needed. Among these concerns is the question of whether the Nation's capability to remain technologically innovative is adequate. In light of this concern, the President has directed that a cabinet-level study of the innovative issue be undertaken, under the overall direction of the Secretary of Commerce. This major review has the aim of proposing policy options to the President for revision of Federal policy, where appropriate, so as to encourage more innovative activity by industry. The agenda of the study is both broad and ambitious. But this breadth reflects the fact that the problem is important and the policies affecting innovation are diverse. Indeed, in light of the importance of the study, much of this annual report is directed at issues touching on innovation.

President Carter has stated:

"The growth of scientific knowledge and its use in the science of mankind is an important concern of our time—we must continue to invest in the development of fundamental knowledge to help meet the challenge and opportunities of the future."

The Administration is dedicated to assuring that our scientific and technological strength continues to grow. We will continue to work to resolve the problems that confront us.

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39. U.S. National Science Foundation. Office of National R. & D. Assessment. Serving Social Objectives via Technological Innovation: Possible Near-Term Federal Policy Options. Washington, U.S. Government Printing Office, 1973. 97 pp.

Introduction, Overview and Summary

INTRODUCTION—SCOPE AND PURPOSE

In the late fall of 1972, the Executive Office of the President (EOP) began to give consideration to ways and means of following up on the President's Science and Technology message of 1972. As one aspect of this activity, NSF's National R. & D. Assessment Program was requested to define and perform a preliminary analysis of possible near-term options available to the Administration to pursue the policies stated in the first Presidential message on Science and Technology to:

Stimulate technological innovation,
Enhance non-Federal investment in R&D and innovation,
Remove barriers to technological innovation,
Increase the application of technological innovation to State, local and regional problems.

There have been a number of studies indicating that the social and private rates of return on investments in research, development and technological innovation are quite large. That is, technological progress and technological innovation play a key role in promoting the economic and social welfare of the nation. The focus of the eight papers in this volume is not on promotion of technology *per se*, but rather on identifying options which serve social objective via technological innovation. The papers revolve around the themes of (1) stimulating the adoption of socially useful technological innovation, and (2) removing barriers that inhibit the adoption of socially beneficial technology.

The eight papers presented here identify and examine opportunities for increasing socio-economic returns through the vehicle of technological innovation. To do so, these papers: (1) examine selected problems and opportunities in the generation and use of technology, and (2) carry out preliminary analyses of near-term options that might be considered with regard to Federal policies toward technological innovation.

The eight papers deal with diverse topics that can be considered individually or in various combinations. Adoption of any of the options depends upon the impact the Administration wishes to make on (1) the problem areas discussed in each paper, (2) the science and technology community, and (3) the policies pronounced in the Presidential message.

The papers discuss the following subjects:

I. Government Loan Insurance for Innovation
II. Federal Regulatory Practice and Technological Innovation
III. Government Purchasing and Technological Innovation
IV. Special Revenue Sharing and Innovation
V. Promotion of Efficiency Energy Use
VI. Technnological Innovation and Small Firms
VII. Training to Facilitate Diffusion of Technology
VIII. Public Technology

The papers discuss the following kinds of questions in assessing the feasbility of options which might be considered in the short term:

Is there evidence of a problem?

Can the causes of the problem be eliminated or the negative impacts lessened?

Can technological innovation assist in ameliorating the problem?

Is there a set of policy options which can be considered in the short run to overcome the problem or take advantage of an opportunity?

What are the pros and cons of the policy options considered?

The short term options discussed here require further examination (e.g., with relevant Federal agencies) should they be attractive to policy makers. Longer-term options also need to be studied and this is the major purpose of the Naitonal R&D Assessment Program. Nonetheless, this exercise has served the following important purposes:

a. Presenting a limited number of options that could be considered for near term action by the EOP in implementing Presidential policy pronouncements.

b. Launching the new National R&D Assessment Program and its analytical staff in a pragmatic exercise of bridging the gap between knowledge from R&D and Federal policy.

c. Beginning the working relationship between NSF and the EOP envisioned in the establishment of the National R&D Assessment Program.

OVERVIEW—CRITERIA AND THEMES

The primary objective in each paper was to analyze alleged problems on opportunities for Federal action highlighting the trade-offs among selected policy options and specified criteria which are employed by policy makers.

The policy options should address a problem (or opportunity) which is within the scope of Federal activity.

The policy options should address a problem of long term importance.

The policy options should address areas in which there are significant public benefits beyond private benefits (externalities).

The policy options should require little in the way of Federal expenditures.

The policy options should not foreclose future options nor should they lead to future problems or significant future costs.

The policy options should be capable of being initiated with relative ease and rapidity, i.e., they should not require a major legislative change nor should they be likely to raise Congressional opposition.

The policy options should be flexible and alterable without serious problems.

The policy options should yield identifiable and measurable progress toward intended objectives in the short term (within three years).

A method for evaluating the policy options should be available.

The policy options should not duplicate existing functions, policies or programs.

The policy options should not conflict with other government policy objectives of equal, or greater, importance than technological innovation.

The policy options should be of a nature that the manpower, institutional and technical requirements to implement them are available or can be obtained in the short term.

The problem and policy options should be such that data and information are available and some preliminary research completed.

The policy options should have few potential negative secondary effects and none of major consequence.

No single option with respect to any given problem is likely to meet all these criteria. The papers use these criteria to assess a set of options, with respect to each problem. Before further work on the options is pursued, those responsible for policy-making should express their preferences for the criteria and options and thereby provide the analysts responsible for further work with their judgment of the weight to be given particular criterial in specified circumstances. The process most likely to yield results is believed to be an interactive one, involving research, analysis, and guidance from policy makers.

While it is difficult to generalize, a number of themes run through these papers. One theme of the papers is that of fostering technological innovation through improved decision-making. For example:

Insured loans—using insured loans to make the risk bearing and decision-making characteristics of lenders more conducive to financing technological innovation.

Regulatory agencies—improving the degree to which Federal regulatory agencies consider the impact on technological innovation in the course of reaching decisions.

Performance specification—utilizing performance specifications to raise the quality and improve the innovative content of government purchases.

Efficient energy use—establishing standards which encourage innovation and more efficient energy utilization.

Small firms—providing improved technological capabilities and information to small firms.

The papers also illuminate the institutional and individual incentive problems that currently impede (or could promote) technological innovation. For example:

Insured loans—increasing incentive to financial institutions to underwrite technological innovation.

Regulatory agencies—lessening impediments (disincentives) in the regulatory agencies serving to discourage technological innovation in industry.

Performance specifications—the lack of positive incentives for innovative government purchasing.

Special revenue sharing—the lack of incentives, due to externalities, to State and local government to undertake technological innovation.

Throughout the papers reveal an underlying theme of conservation of resources of efficiency in achieving selected objectives. For example:

Insured loans—the conservation of Federal financial resources through programs designed to support and encourage non-federal funding of technological progress.

Performance specification—the conservation of Federal and other government financial resources by more efficient purchases through better use of technology.

Special revenue sharing—the maintenance of Federal incentives for technological innovation at the state and local level.

Energy conversion—the conservation of resources through more efficient energy utilization.

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40. U.S. National Science Foundation. Office of National R. & D. Assessment. Technological Innovation and Federal Government Policy: Research and Analysis of the Office of National R. & D. Assessment. Washington, 1976. 73 pp.

Some Research Findings

Some of the initial findings of RDA's research and analysis are summarized below. These are discussed more fully in Parts II through IV, at the pages noted.

PART II. GOVERNMENT INVESTMENT IN INNOVATION

There is persuasive empirical evidence that R&D and technological innovation have had a significant position effect on the growth of productivity, and economists have argued that the U.S. is probably underinvesting in civilian sector R&D from the point of view of economic growth and productivity. (pp. 11–12)

Few firms keep accounting records in such a way that they could easily respond to a mailed questionnaire about their expenditures for "innovation." Thus, it is difficult to measure the amount and type (rate and direction) of innovation in private firms. Information about firm's expenditures for innovation can, however, sometimes be obtained through intensive field work. (pp. 12–13)

An analysis of 17 industrial innovations revealed great variability in the rates of return firms obtained from innovation, with a median rate of return (before taxes) of about 25 percent. Total rates of return to society were twice as high as the private rates of return to the firm itself. A significant proportion of innovation produced very low private returns but high returns to society. (pp. 13–16)

PART III. GOVERNMENT REGULATION OF BUSINESS

No consensus exists as to whether regulation has, on the whole, been beneficial or detrimental to the overall rate and direction of innovation in industries subject to regulations, although some authors have concluded that economic regulation is likely to have a detrimental effect. Although we may not necessarily expect general conclusions to emerge on the effects of government regulation on technological innovation, limited conclusions may be possible at lower levels of aggregation, such as within industries, areas of technology, or types of regulation. Examples of regulations which have inhibited and encouraged technology are available. (pp. 19–22)

The importance of patent rights for a firm's innovative activity varies significantly from industry to industry. The variance in the importance of patents may be in part due to the existence of trade secrecy laws, which provide another means of protecting process inventions. (pp. 26–27)

In many industries, small to medium sized firms conduct research more efficiently than large firms. Increases in firm size, beyond some intermediate size, do not appear to be especially conducive to increased R&D intensity. Medium- to large-sized firms, however, may offer economies of scale in later phases of innovation and are better able to exploit or develop R&D findings. (pp. 27–28)

PART IV. THE TRANSFER AND USE OF TECHNOLOGY

The types of individuals and groups involved in technological innovation in State and local governments vary considerably across functional or service areas; and citizen and States differ widely in their needs and in conditions providing stimuli to innovation. Hence, Federal efforts focused on helping cities and States make decisions on whether and how, to utilize new technology in the solution of problems may be more effective than stimulating cities and States to adopt a given research product or technology. (pp. 31–34)

There is no clear-cut relation between foreign direct investment and "R&D intensiveness" of industries; in contrast, international licensing tends to vary directly with the "R&D intensiveness" of industries. One factor which tends to inhibit the amount of foreign direct investment and licensing is that benefits to both selling and recipient firms are limited by the substantial costs often entailed in technology transfer. Available evidence suggests that foreign direct investment in general makes a small contribution to international diffusion of technology. (pp. 36–39)

In the short run, technological change has altered the skill requirements in specific jobs and industries, but often this structural unemployment has been accompanied by employment opportunities in other industries and occupations. Privately developed programs have handled worker adjustment problems quite well in a majority of cases, particularly those occurring in large, unionized firms. In contrast, employees of small and/or nonunion establishments and population groups which are more severely or more frequently affected by change rely more on public mechanisms, such as publicly provided income support and retraining. (pp. 39–41)

PART V. CONCLUSIONS

To improve Federal R&D and technological innovation policy, it is necessary to gain greater understanding of the incentives which influence innovation, the processes by which these influences work, and the societal outcomes of innovation. In the absence of this knowledge, policies may be based on (1) incorrect evaluations of the incentives influencing innovation and (2) incorrect assumptions about cause-effect relationships.

The initial series of studies sponsored by the R&D Assessment Program included state-of-the-art assessments of knowledge about technological innovation to determine whether synthesizing scattered pieces of knowledge could provide useful inputs to policymakers. The results of these studies, as well as a few empirical studies, have been highlighted in this report. A statement from a report to RDA sums up the state-of-the-art: "The state of social science ilterature on matters relating to technological innovation is far too undeveloped to warrant many strong conclusions with respect to government policy to alter innovative behavior." And,

"The main lesson to be learned from the literature is that numerous factors are likely to affect the innovative behavior of firms . . . Since the conditions in which firms operate vary with respect to these factors, the only firm conclusion about generalized. economy-wide policy is a negative one: no universal policy covering firms in differing market and technological environments is likely to lead to an efficient rate and direction of technological innovation." [48, Noll, et al., 1974]

These conclusions are echoed in the statements made earlier in this report, in phrases such as: "is not thoroughly understood," "is elusive," "not capable of leading to generalization," "is still subject to debate," and "tentativeness of the findings." While reasons for the tentative state of our knowledge have been mentioned throughout the report, the remainder of this part reviews some of the research and measurement problems which beset the existing state of knowledge, and indicates areas in need of research.

THE STATE OF THEORY

A basic problem in understanding technological innovation arises from an absence of well established cause and effect relationships, i.e., an absence of good theory. Because of inadequate theoretical understanding, i.e., an inadequate basis for sorting out important factors from unimportant ones, dependable generalization often cannot be made about the effects of government policies on innovation (or, for that matter, about the effects of numerous other variables on innovation). In the absence of an established theory that explains why events occur or how causes are linked to effects, resolving different or conflicting empirical findings (much less different assertions) is difficult. Moreover, theory helps define what variables to measure, how inputs and outputs are related (i.e., cause and effect), and how to measure the variables. Given this outline of the role of theory in general, what is the state of theory relating to innovation?

Within limits, existing theory can predict the expected response, on average, of firms and individuals to alternative government policies. For example, economic theory allows one to predict deductively that on average a tax rebate for industrial R & D may increase aggregate R & D inputs, but theory indicates neither the amount of increment in R & D activity from a given tax rebate nor the effects on outputs. Empirical analysis helps clarify these latter outcomes.

Among the specific problems of current theory are:

(1) R & D and innovation may not be the same thing from industry to industry, nor over time in the same industry. A similarity of structural conditions, individual incentives, and important variables may not exist across industries or in different time frames. Thus an extensive and versatile theory is needed.

(2) Social and behavioral science theory tries to predict human behavior, i.e., inputs to the innovation process rather than outputs, and does not deal with the prediction of technical advance per se.

(3) There are no well-defined criteria with which to formulate normative judgments about the rate and direction of innovation.

Given the state of theory about innovation, does such theory have anything to offer policymakers now, and can it be improved to provide a better foundation for understanding innovation in the future? In response to the first question, existing theory would appear to be helpful in at least two major ways.

First, although we do not know for sure what the effects of a given policy on innovation will be, theory can help to identify at least some of the important assumptions involved. For example, we know the incentive-disincentive structures involved should be studied and the predicted changes in them analyzed in order to estimate the likely effects of a policy. Existing theory does provide us with enough knowledge of human and institutional behavior that we may question casually assumed results expected to flow from particular policy prescriptions.

Second, we do have a considerable body of theory from which to examine and predict movement from one technological position to another, incorporating changes in the use of known technologies. There is a certain amount of understanding of the diffusion of *known* technologies, as opposed to the creation of fundamentally different or new technologies. Even here, however, the lack of understanding of the governmental processes by which policies are translated into change in incentives facing firms limits our ability to predict the effects of government policies on diffusion [48, Noll, et al., 1974].

If we are to go beyond statements and predictions about the use and diffusion of known technologies (the area of our greatest knowledge) to statements and predictions about the creation of new technologies, theoretical developments are necessary. These may be approached both deductively (largely a function of groups other than RDA) and inductively, that is, by supporting thorough case studies of innovation, especially as affected by government policy. The latter approach would provide policy information in a very narrow area (but not generalizable without many such studies) and would provide the building blocks for more comprehensive understanding as well as some hints for the development of theory. In addition, some existing theories, which have not been verified empirically could be tested for particular cases.

As this report indicates, we have only partial answers to many of the research and policy issues raised above. This situation is frustrating for the policymaker who is faced with immediate decisionmaking relating to R&D and other aspects of innovation (as well as to administrators of a research program which is designed to be "policy-relevant".) We have tried, nonetheless, to emphasis some of the "hints" or glimmers of knowledge that *do* exist about R&D and innovation, and their policy implications. It is hoped that the reader has developed a greater unerstanding of the complex nature of technological innovation processes and the various factors that impinge on these processes, and also some insight into options that do and don't warrant further consideration. While exact answers may never be available, policymaking is not an exact science and the goal is to gain sufficient knowledge to enable Federal policymakers to provide better incentive to foster scientific and technological activities to achieve national objectives.

One of our investigators made a statement about his own particular area of research that could well be applied to the entire study of technological innovation: "In the quest for this knowledge, our position is similar to that of a diner just starting to eat an artichoke. We have tasted a leaf or two, but most of the discovery is ahead of us. Innumerable leaves remain to be peeled off before the heart is reached" [56, Stobaugh, 1974]. The R&D Assessment Program, through its research and analysis efforts, is trying to help peel off some of the remaining leaves.

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41. U.S. Panel on Invention and Innovation. Technological Innovation: Its Environment and Management ["Charpie" Report]. Washington, U.S. Government Printing Office, 1967. 90 pp.

SUMMARY

In accordance with its charter, the Panel considered three main factors affecting invention and innovation: taxation, finance, and competition. On the basis of its analysis, the Panel concluded that there was no need to recommend any major changes in the present laws governing these three areas. However, it did make a number of specific proposals aimed at improving the environment for invention and innovation.

With respect to the field of taxation, the Panel made several specific recommendations which it felt could provide justifiable encouragement to inventors and innovators. Among these recommendations are proposals providing for a more equitable treatment of innovation losses, an improvement of the stock option to make it a more effective instrument for attracting critically important management personnel to fledging firms, and a reasoned approach to tax-deduction problems posed by several other areas of the tax laws.

The Panel found no reason for proposing any new federally supported programs to furnish venture capital for the financing of new, technologically based enterprises. It did, however, make recommendations concerning the communication of venture-capital opportunities and the establishment of an effective Federal spokesman for such enterprises.

The Panel's review of the interaction between competition and innovation showed a need for greater understanding of this interaction and improvements in the coordination of antitrust and regulatory policies affecting both competition and innovation. No new antitrust or regulatory legislation was recommended, but the Panel did recommend, among other proposals, the establishment of a group to serve as an advisory resource to the antitrust and regulatory agencies, as well as a strengthening of the professional staffs of these agencies.

Throughout its review, the Panel was impressed by the need for promoting a basic understanding of the innovative process in all sectors of our society. The Panel felt that it would be highly desirable to encourage educational programs, studies, and regional seminars to further this understanding. Accordingly, the Panel's concluding recommendation proposes a White House conference on technological innovation, to dramatize the importance of this vital process, and urges that this conference be followed by a nationwide program for broadening recognition, understanding, and appreciation of the problems and opportunities associated with technological change.

42. Universities-National Bureau Committee for Economic Research. The Rate and Direction of Inventive Activity: Economic and Social Factors. A conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth for the Social Science Research Council. Princeton, Princeton University Press, 1962. 646 pp.

INTRODUCTION

(By Richard R. Nelson)*

Some Problems Treated in this Volume

Due to the large number of papers included in this volume and their diversity, it seems more useful to provide a guide to the reader by discussing some of the issues treated and some of the different points of view expressed than to present an annotated bibliography. In the discussion which follows a number of papers will be considered under two or more topic headings, and the order of treatment will follow the chapter sequence only roughly.

THE CLASSICAL ECONOMICS APPROACH AND THE BLACK BOX

Almost all the papers in this volume were written by economists and tend to reflect the economists' interest in economic growth and in problems of efficiency. This is certainly so of the papers in Part I, which deal with Problems of Measurement and Definition. Both Kuznets and Sanders are interested in defining inventive activity so that the outputs, "inventions," somehow measure an important contribution to technological change, and so that the inputs, resources directed toward inventive activity, may be fitted into a more or less classical economic analysis. Although the two authors differ quite markedly in the extent to which they believe that convenient and useful measures of inputs and outputs exist, the papers are very similar in point of view.

This point of view is essentially that of classical economic analysis, and many of the papers presented at this Conference are similar in that they are attempts to analyze inventive activity with the traditional tools of economics. Machlup's paper examining the supply curve of inventions and Fellner's paper on the profitability of various sorts of inventions certainly fit this mold.

Kuznets and Machlup point out, however, that there are some difficult problems involved in applying classical economics to inventive activity. One particularly important problem results from the fact that there may be great differences in the creativity and productivity of different inventors. How many average inventors does it take to equal one Edison? This fact seriously complicates the analysis of the supply of inventions and indicates that psychological and sociological data may be urgently needed for economic analysis of inventive activity.

MacKinnon's study indicates that such data may be obtainable and useful. MacKinnon examines the intellect and motives of a group of inventors and compares his results with existing data on other creative groups. His findings may have considerable bearing on the extent to which there is a sizable group of potential inventors which might be tapped by an increase in rewards, and hence on an analysis of the supply of inventions.

Minasian's paper presents encouraging evidence that classical economic theory can be applied fruitfully to inventive activity. Minasian's dependent variable is the one which is of real interest to most economists concerned with inventive activity—technological change. His independent variable is the one many economists would look to as the conveniently measured input to inventive activity—expenditure on R and D as defined by the National Science Foundation. He finds that a quite strong relationship exists between R and D expenditure and subsequent increases in productivity.

Save for analysis of the incentives of individual firms within competitive industries, the link between increased productivity and increased profits can be a quite complicated one. However, Minasian finds a strong relationship between increased productivity and subsequent profits for a firm. This result suggests that for some purposes economists may be justified in treating the allocation of resources to inventive activity within essentially the same framework as has been used to treat the allocation of production inputs. Fellner does just this. He is in-

*The Rand Corp.

terested in how market incentives tend to "slant" inventions toward various factor saving configurations. Do high wage rates tend to stimulate inventions that are relatively labor saving? High interest rates, inventions that are relatively capital saving? Although he asks the question in terms of aggregative factors and factor prices, his analysis can easily be generalized in much greater factor detail. And although his conclusions are geneerally negative, his framework of analysis implies that inventors or R and D managers can predict are able to predict what the new production function will look like. The assumptions Fellner requires are much stronger than the evidence provided by Minasian.

Several of the papers of Part V, particularly the Marshall-Meckling paper and the Klein paper, throw serious doubt on the ability of inventors to predict as closely as is required by the Fellner model. The concern of these papers is primarily with R and D efficiency, and the authors have attempted to look quite deeply at the insides of the black box—at the R and D process itself. The Marshall-Meckling paper shows that, in military R and D at least, the ability to predict the cost, performance, and development time of new inventions is sorely limited. Klein argues that this fact, plus the fact that as development progresses estimates get better, imply that the whole strategy of maximization in R and D may be different from that in production. If these conclusions are generally correct, prediction models based on the assumption of expected profit maximization, that is, models which attempt to explain changes in allocation by assuming optimal strategies on the part of entrepreneurs as a function of prices, etc., might well consider a wider class of behavior than is treated in classical economic analysis.

THE CONCEPT OF PARALLEL INVENTIVE EFFORTS

Klein argued that the type of uncertainty inherent in R and D implies that decision makers might be wise to run several R and D efforts in parallel. Since the concept of parallel inventive efforts, as formulated by Klein, Meckling and Marshall, and Arrow, and as described by Marschak, has few close analogies elsewhere in economic theory, it seems worthwhile to spell out the logic behind it.[16] Assume that a certain value (a function of demand and cost variables) is attached to the successful invention of a device which meets specific requirements—say a long-range aircraft or a high quality soundscriber. Assume that a company or a group of inventors is interested in developing such a device and knows that there are a number of different possible designs that are likely to meet the requirements more or less adequately if enough inventive time and effort are expended. The utility, production cost, and invention cost of the different possible approaches are likely to differ significantly, but presently it is not at all clear which approach is best. However, it is expected that as work proceeds on any particular approach a great deal will be learned about its prospects and cost. Information and work accomplished are joint products.

It can be shown that it may be good strategy for the group of inventors initially to diversify their efforts and undertake parallel work on several alternative approaches—run them in parallel. Then, as information accumulates and more reliable rankings of the alternative designs are obtained, the effort should narrow down to the more promising designs. This conclusion is certainly intuitively reasonable, but the proof of it can be quite complicated.

Under certain assumptions it can be proved that the number of alternatives which should be run in parallel is larger (1) the greater the payoffs from successful invention, (2) the greater the rate of "learning," (3) the lower the costs of the initial stages of effort, and (4) the greater the "differences" in the alternative approaches.[17]

The concept of parallel inventive efforts has been studied formally only in the context of normative analysis for a company or organization. The extension to normative analysis for a society has not been undertaken, and the framework has not been used formally as part of a positive theory. However, the concept does suggest certain positive implications.

In particular, it might well be that a rightward shift in the demand curve for a particular product would have its major impact by increasing the number

[16] Nelson, "The Economics of Parallel R and D Efforts," *Review of Economics and Statistics*, Novemebr 1966.

[17] The rate of "learning" is defined as the rate of reduction in the expected squared error of estimate of a relevant parameter; the "differences" in alternative approaches are defined in terms of correlation coefficients.

of independent efforts to invent close substitutes or reduce production costs. Schmookler's study of inventive activity in four industries supports this conjecture, and he presents an analysis of the incentive mechasism at work. Machlup also deals with the multiple effort nature of inventive activity and points out that an increase in the number of parallel efforts might result partly in a greater number of new products or processes accepted by the economy, partly in greater speed in the achievement of a satisfactory breakthrough, and partly in a higher quality of inventions the economy finally accepts. One implication of this might be, as Machlup suggests that, as inventive activity in an area increases, the ratio of patents issued to resource inputs will fall because an increasing fraction of the resulting inventions will be duplicates, or near duplicates. And it well might be that by exploring just what sorts of responses are likely to occur as a result of an increase in expected profits, the predictive value of the theory could be significantly enhanced over the simple statement that inventive effort will increase.

PROFITS FROM INVENTIONS

The papers of Schmookler, Enos, Peck, Marschak, and Nelson indicate that, as a first approximation, one might ignore the complications suggested by Klein and try to explain the allocation of inventive effort by a quite simple maximization model. Schmookler is able to explain a considerable proportion of the variation in patenting in his four industries by variations of demand, and profitability. Enos finds that in the field of petroleum refining invention was extremely profitable, both ex ante and ex post. Peck finds that the different kinds of inventions in the aluminum industry were supplied by those groups of firms we would expect to be most likely to profit from them. Marschak finds that Bell Telephone Laboratories had a pretty good idea of what it wanted when it set out to develop a new communications system, and that the decision was quite rational (cost reduction oriented). Nelson shows that, even in a field with so complex a set of motives and controls and so uncertain an environment as basic research, similar circumstances prevailed. Thus the inventors of the transistor were looking for an amplifying device, among other things, and there were good reasons for their belief that a solid state amplifying device would yield significant practical payoffs.

Although these examples suggest that expected profit may be a very useful independent variable in a model explaining the allocation of inventive activity, they also suggest that a quite detailed and sophisticated analysis is required in order to understand where profit opportunities lie in the fields of invention. For example, in Marschak's study it is clear that the demand curve for communications capacity was shifting to the right, but the scarce factor whose opportunity cost was rising was the unused portion of the frequency band. The inventive effort was directed toward designing equipment to use previously unused frequencies. Although the initiation of the development is easily explained using the conventional language of economists, only someone quite familiar with the communications industry would think of frequency bands as a factor of production.

To further complicate the problem, Rubenstein's paper suggests that organizational factors may be very important in determining a firm's perception of, and reaction to, profit opportunities.

In order to have a useful theory relating inventive activity to perceived profit opportunities we must be able to answer the following kinds of questions: What factor costs are relevant to the profits from successful invention? Do the shapes of the supply and demand curves figure in an important way? What are the complements of invention? The substitutes?

The Thompson and Worley data reflect our present lack of understanding of the conditions underlying high R and D profitability. Thompson relates the geographical distribution of persons receiving patents to the extent of urbanization and to industrial structure. Worley explains the changing composition of the 100 largest R and D employers by relating R and D employment to the size of the firm, and to the industry involved. It is clear that some industries are much more R and D intensive than others but the reasons are not apparent. To say that in these industries R and D is extremely profitable is to beg the question. Brozen relates R and D profitability to past expenditure on basic research, but it seems worthwhile to ask why some industries have in the past spent more on basic research than others. To explain the differences we can fall back on institutional and cultural variables, or say that some industries are linked more closely to fundamental science than others. But what do we mean by that? It is not at all clear.

Schmookler's analysis suggests that invention and new capital equipment may be complementary relative to variable factors of production. This is scarcely a surprising result, but an important implication is that economists had better be wary in making any sharp conceptual split between capital formation and technological change as factors increasing output per worker. Clearly it will require a quite sophisticated type of analysis to disentangle the factors that contribute to high R and D profitability.

Adding to the difficulty of predicting and explaning where profitable opportunities lie is the problem of external economies discussed by Arrow and others. This problem is more appropriately discussed under the topic "Invention and Policy," but it should be said here that, to the extent that different market structures and institutions affect R and D profitabiilty, a predictive theory must consider these variables.

NONMARKET FACTORS

In his analysis of problems of public control, Markham raises the point that a very large fraction of our R and D effort is at least partially divorced from the incentives and controls of the market. On the demand side, the source of over half our R and D demand is the federal government. On the supply side, much R and D activity in conducted in organizations (universities, government laboratories, etc.) whose goals include many variables other than profits. It is important to understand these nonmarket controls and incentives.

Cherington's paper is a description of how military R and D decisions are made. It is a study of how a complex organization, attempting to maximize a welfare function involving many variables not easily measured by money and operating in an environment of great uncertainty, gains information and advice and comes to make choices.

Merrill's paper examines organization and the decision making process in basic science and in several other sectors that are linked only loosely to the market. He finds that the allocation of effort in basic academic science is determined in part by the interests of individual scientists and in part by the professional judgment of an elite who have considerable control over resources and rewards. The "welfare function" being maximized involves the conceptually vague but seemingly quite operational concept of promise to advance understanding. Nelson, in his study of the Bell Telephone Laboratories, shows that the mechanisms described by Merrill work in industrial basic research laboratories as well as in universities. Merrill also examines the structure of incentives and controls in medical research, in university engineering research, and in governmental agricultural research, all sectors where allocation is not directly guided by a market.

The Schmookler and Nelson papers present quite different evidence on the role that science plays in invention. Schmookler finds little evidence that advances in scientific knowledge contributed much to the inventions of the industries he has studied. To the extent that science did play a role it was a permissive one—as a reference book determining the skill with which persons concerned with practical problems were able to surmount them. Nelson's study shows science in a more active role, with advances in knowledge triggering inventive activity, generating a search for problems to which the new knowledge could be applied. It seems likely that the differences here reflect basic differences in the nature of the industries. The electrical communications industry is much more closely related to fundamental science than is railroading or papermaking. But this statement begs the question of what "closely related to fundamental science" means.

Siegel discusses a number of the relationships between science and invention. He attempts to relate both to the concept of information. A large number of the papers in this volume seem to be approaching the view that research and inventive activity are essentially activities aimed at creating information (see the Arrow comments). One would suspect that, in the future, research on the economics of invention will draw more intensively on the concepts of information being developed by economists, decision theorists, and mathematicians.

INVENTION AND POLICY

The notion that conditions for R and D efficiency may be quite different from conditions for production efficiency is reflected, but only partially, in the Arrow and Markham papers dealing with normative aspects and public policy. Arrow focuses on three important problems. One is the conflict between static conditions and longer-run efficiency conditions raised by the very low social cost of using knowledge, as opposed to the quite high cost of producing it. The problem is an old one in economics and in the past has been argued in the context of such examples as optimum bridge tolls. In R and D, however, certain special and quite complicated problems of appropriability of product seem particularly important. Arrow also is concerned with the welfare implications of the risk in R and D. It can be shown that to the extent that individuals can avert risks and no "insurance" is available, less will be spent on risky activities than is socially desirable.

A third major problem is that of external economics. Arrow, Kuznets, Machlup, Markham, Merrill, and Nelson all present arguments or evidence that, given existing institutions, inventive activity generates values which cannot be captured by the inventor. The problem seems particularly serious toward the basic research end of the spectrum.

Klein might argue that Arrow has not gone sufficiently far in admitting and examining the implications of certain properties of the knowledge producing industries, particularly the nature of the efficiency conditions. The problems raised by the efficiency of running parallel approaches may be particularly nasty. Is it efficient to run the invention industry as a lottery? If only one is to win the prize but each competitor can benefit from the ideas of the others, what mechanisms will generate an optimum flow of information? What of the many situations in which successful inventors and inventions spring from the ruins of unsuccessful ventures? To the extent that technological change builds on itself, what mechanisms can gain for an inventor some share of the profits from subsequent rounds of inventions to which his ideas contribute?

Markham is concerned with the conflict between antitrust policy and policies designed to sponsor a more rapid rate of technological change. The papers of this volume present conflicting evidence on the role of the large corporation. The Marschak and Nelson papers seem to indicate that in R and D size is a great advantage. It is difficult to imagine either the development of the T.H. system or the research which created the transistor being carried out in a small laboratory. These papers show that economies of scale seem to result from the ability of large laboratories to make profitable use of what would be external economies in a small laboratory, their ability to make profitable use of a wide range of expertness (division of labor) and their capacity to carry a large portfolio of projects (reduction of risk).

At first glance, Mueller's study seems to give conflicting evidence. He finds that only a small proportion of Du Pont's major product and process innovations stemmed from Du Pont inventions. (Three important exceptions are Dacron, Nylon, and Neoprene.) However, Mueller's evidence does not clash sharply with the theory that the large laboratory in the large and diversified company has a comparative advantage in many fields of inventive activity, for many of Du Pont's innovations stemmed from inventions of (other) large laboratories. Effective public policy certainly depends on better understanding of the economies and diseconomies of scale and diversification in the invention industry.

The organization of papers in this volume is significantly different from the order of presentation at the Conference. Further, because of duplication of content, or because the material is being published elsewhere the following papers have been compressed considerably from their Conference versions: Brozen, Cherington, Machlup, MacKinnon, Rubenstein, Sanders, Siegel, and Worley. The more extensive versions of these papers can be obtained by writing to the authors.

Appendix B

The National Science and Technology Policy, Organization and Priorities Act of 1976 as enacted to provide a comprehensive national science policy and to provide the president with a science advisory apparatus. Reorganization Plan No. 1 of 1977 abolishes the Intergovernmental Science, Engineering, and Technology Advisory Panel, the President's Committee on Science and Technology, and the Federal Coordinating Council for Science, Engineering and Technology and transfers to the president all functions vested in the Director of the Office of Science and Technology Policy. Executive Order 12039 of February 24, 1978 transfers certain functions from the Director of the Office of Science and Technology Policy to the Director of the National Science Foundation, abolishes the

panels and committees listed in the Reorganization Plan No. 1 and reestablishes the Intergovernmental Science, Engineering, and Technology Advisory Panel and the Federal Coordinating Council for Science, Engineering and Technology. Committee Print CP-840, House Committee on Science and Technology, Address: 2321 Rayburn House Office Building, Washington, D.C. 20515.

Carter, Jimmy. *National Academy of Sciences. Remarks at the Academy's Annual Meeting*, April 23, 1979. ". . . reaffirm to you my commitment to basic research . . . strengthen basic research in the individual Federal agencies . . . tried to resolve . . . problems of unnecessary Government regulation and excessive bureaucratic paper shuffling . . . need innovation on a broader scale . . . must change Government practices that thwart innovation, while encouraging Government policies which encourage the development of new products and new processes. . . ." Weekly Compilation of PRESIDENTIAL DOCUMENTS. Address: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Carter, Jimmy. *Science and Technology—Message to the Congress*. March 27, 1979 ". . . a science and technology policy for the future . . . This message to the Congress: describes the Administration's policy perspective on science and technology and the roles of government, industry, universities, and the public in support of science and technology; highlights some of the most important science and technology initiatives undertaken in my Administration . . ." Weekly Compilation of PRESIDENTIAL DOCUMENTS. Address: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Carter, Jimmy. *Industrial Innovation Initiatives—Message to the Congress Transmitting Proposed Initiatives*. October 31, 1979. ". . . I am announcing measures which will help ensure our country's continued role as the world's leader in industrial innovation. These initiatives address nine critical areas: Enhancing the Transfer of Information; Increasing Technical Knowledge: Strengthening the Patent System; Clarifying Antitrust Policy; Fostering the Development of Small Innovative Firms; Opening Federal Procurement to Innovations; Improving Our Regulatory System; Facilitating Labor/Management Adjustment to Technical Change; Maintaining a Supportive Climate for Innovation. Weekly Compilation of PRESIDENTIAL DOCUMENTS. Address: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Carter, Jimmy. *Economic Renewal Program—Remarks Announcing the Program*. August 28, 1980. ". . . the steps that I describe this afternoon will . . . put people back to work, reduce taxes, increase public and private investment in the future, and constrain inflation all at the same time. . . . There are four major goals . . . First, increase private and public investment to revitalize America's economy. Second, create a forward-looking partnership between government and the private sector. . . . Third, to help people and communities overcome the effects of industrial dislocations. And fourth, to help to offset the rising individual tax burdens in ways which do not rekindle inflation. . . ." Weekly compilation of PRESIDENTIAL DOCUMENTS. Address: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Science and Technology Report 1980. National Science Foundation. June 1980. This second annual report on state of science and technology, mandated by the National Science and Technology Policy Act of 1976 and prepared by the National Science Foundation, examines strategic issues concerning science and technology, Federal funding of research and development, R&D and economic progress, comparative performance of U.S. technology, basic research in industry and issues in support of academic science. Committee Print, House Committee on Science and Technology, Address: 2321 Rayburn House Building, Washington, D.C. 20515.

Technology Innovation for a Dynamic Economy. Christopher T. Hill and James M. Utterback, editors, Center for Policy Alternatives, M.I.T. 1979. This book, composed of eight reports prepared for the Department of Commerce, identifies and describes the process of innovation and offers policy recommendations which might be adopted to ensure that the U.S. economy remains responsive to economic and political changes in the long term. Address: Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, New York 10523.

Stimulating Technological Progress, Research and Policy Committee for Economic Development, January, 1980. This research report and policy statement of the CED maintains that technological progress underlies economic and social progress in the United States. To ensure the vitality of a technologically based economy four policy prescriptions are offered: tax policy changes favoring in-

vestment, reforming the patent policy system, direct federal support of research and development, and reducing regulatory constraints on innovation. Address: Committee for Economic Development, 477 Madison Avenue, New York, New York 10022.

Industrial Innovation, Mary Mogee and Wendy Schacht, June 16, 1980. Several issues concerning industrial innovation are reviewed in this CRS Issue Brief. These issues include: Is U.S. industrial innovatiton declining in a meaningful sense, relative to historical levels or to the Nation's Major trading partners? Can the current economic situation be improved by stimulating industrial R&D and innovation? The issues are defined and analyzed, and selected legislation from the 96th Congress is examined. Address: U.S. Library of Congress, Congressional Research Service, Washington, D.C. 20540.

Science Indicators: Improvements Needed in Design, Construction, and Interpretation. U.S. General Accounting Office, September 25, 1980. This review of Science Indicators, 1976, conducted for the Joint Economic Committee, recommended that the National Science Board, "should emphasize a more conceptual approach which first identifies what will be measured, and then generates the appropriate data." PAD-79-35. Address: United States General Accounting Office, Washington, D.C. 20548.

Antitrust, Uncertainty and Technological Innovation. Ginsberg, Douglas H. National Academy of Sciences, 1980. This monograph, the third in a series on technological innovation, is the product of a workshop held in December, 1978 which examined the extent to which antitrust policies unnecessarily inhibit innovation activities. The effects of policy uncertainty on technological innovation, on the joint R. & D. ventures and on patent law are reviewed, and recommendations to the Federal Trade Commission and the Department of Justice are offered. Address: Office of the Foreign Secretary, National Academy of Engineering, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

The International Technology Transfer Process, Robock, Stefan. National Academy of Sciences, 1980. This report is the product of a workshop held in February, 1978 on the anatomy of international technology transfer. The technology transfer process is defined and described. Three issues of improving the data base for policymakers are presented, and a call for improved policy-relevant information is made. Address: Office of the Foreign Secretary, National Academy of Engineering, 2101 Constitution Avenue, NW., Washington, D.C. 20418

The Reindustrialization of America. Business Week, June 30, 1980. This special issue of Business Week examines causes of the decline in American industry and offers a solution for rebuilding U.S. economic power based on a "new social contract" between business, labor and the Federal Government. Address: McGraw-Hill Publication Company, Reprint Department N-1, Princeton Road, Heightstown, N. J., 08520.

Advisory Committee on Industrial Innovation—Final Report, U.S. Department of Commerce, September 1979. This is the final report of an advisory Committee of more than 150 representatives from the industrial, public interest, labor, scientific, and academic communities who considered the effect of Federal policies and programs upon industrial innovation, and, specific recommendations for changing existing policies and programs or initiating new ones in order to enhance the state of industrial innovation in the United States. Address: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

TWO DECADES OF RESEARCH ON INNOVATION: SELECTED STUDIES OF CURRENT RELEVANCE

By Richard Kremer and Mary Ellen Mogee *

CONTENTS

INTRODUCTION

During the past two decades, policy analysts, economists, social scientists, historians, and Government agencies have devoted a considerable amount of study to the processes, contexts, and impacts of technological innovation. In addition to deepening the knowledge of the innovation system, these researches have produced many policy recommendations for stimulating innovative activity. Despite their continued relevance, many of these recommendations have remained largely unevaluated and untried by public policymakers. This chapter assembles and summarizes in abbreviated form 42 studies from the past two decades, and focuses especially on the policy recommendations contained therein. It was felt that prior to further analysis and synthesis of policy options for stimulating innovation, it would be beneficial to have a rather thorough overview of past efforts.

Based on consultation with a number of research, development, and innovation analysts, the 42 studies were selected using the following criteria, interpreted subjectively:

(i) Major studies dealing with the entire innovation system, and not only isolated factors within it;

(ii) Studies containing explicit *public* policy recommendations, or contributing to the general understanding of innovation; and

(iii) Studies recent enough to be of continuing relevance to policymaking.

These criteria are admittedly subjective, and the list of 42 studies cannot be regarded as comprehensive. Nonetheless, it seems unlikely that any studies that have been overlooked would significantly alter the

*Science Policy Research Division, Congressional Research Service, Library of Congress.

overriding thrust of this chapter, viz, that many excellent analyses and relevant recommendations are yet to be considered by policymakers. Current studies, such as the President's Domestic Policy Review of Industrial Innovation or the study of technology policy by the Committee on Economic Development are not covered here, since they are included elsewhere in this report volume. This chapter serves as background to these current studies, and to Mogee's analytical review of the state-of-knowledge, which also is included in this volume.

This chapter consists of three sections. The first section lists 205 policy recommendations for stimulating innovation, categorized into 14 policy areas, which have been extracted from the 42 studies. Some of these appear to overlap; others may be contradictory. Some are broad and general; others are narrowly focused. As a package, however, they represent candidates for analysis because of their continued relevance and likely efficacy in stimulating innovation.

The second section arrays these recommendations against the action parties who would be involved in determining and executing the policies implied by the recommendations, and against whom the executed policies would impact. The third section presents brief abstracts of the central points of the 42 studies. Scanning these 42 short paragraphs will provide a panoramic view of the decade-plus of literature on innovation.

An adjunct to this chapter appears as an appendix to the area study. This appendix reproduces the core material from each of the 42 studies included in this chapter, in the form of excerpts of the executive summaries, principal findings, recommendations and conclusions, or other pertinent sections. These reproduced original materials permit the reader to select specific items and to view them directly without interpretation by the study team.

Taken together, these selections provide the main sources for much of the current understanding of the innovation system, and illustrate the many interconnected issues which must be faced by policymakers seeking to stimulate technological innovation. Likewise, the identification of action parties connected with the recommendations indicates how many segments of the Federal Government intersect with the innovation system, and suggests the need for holistic, comprehensive policymaking. No in-depth analysis of the recommendations, however, has been attempted here.

I. Policy Recommendations for Stimulating Innovation From Two Decades of Innovation Studies

The following recommendations for stimulating innovations have been extracted from the 42 studies included in this collection. The numbers in square brackets following each recommendation are keyed to the 42 studies numbered in section III of this chapter, and indicate which study proposed the recommendation. When several studies propose the same recommendation, their respective numbers have been listed. Table 1, following the recommendations, indicates the relative distribution of recommendations among the 14 policy areas into which they have been categorized.

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Policy Recommendations for Stimulating Innovation (Corresponding to Table 1)

TAXATION

1. Allow small firms to carry forward losses against profits of succeeding 10 years (change Internal Revenue Code (IRC), Sec. 172). [1, 9, 31, 41]
2. Liberalize qualified stock option rules for small firms by (i) extending option period to 10 years [9, 41], (ii) reducing holding period required to receive capital gains treatment to 6 months. [9, 31, 41]
3. Relax criteria for deducting Research & Development (R. & D.) expenses for the amateur inventor. [41]
4. Allow successful inventor to write off earlier development costs over a period of 5 years. [41]
5. Give professional inventor the same capital gains break as amateur inventor on grants of patent rights limited to a specific field of use (change IRC, sec. 1235). [41]
6. Allow R. & D. expenditures to be written off even if unrelated to the taxpayer's current products or processes. [41]
7. Increase writeoffs for taxable purchases of technological assets. [23, 41]
8. Increase tax investment credit for R. & D. plant to 25 percent. [9, 32]
9. Increase tax depreciation allowance for R. & D. plant. [32]
10. Trade present tax credit for R. & D. plant for credit or cash payments for all expenditures on industrial R. & D. [32]
11. Provide new special tax credits or equivalent cash payments to industrial R. & D. performers. [32]
12. Provide new tax credit or equivalent cash payments for incremental R. & D. [3, 5, 32]
13. Provide new tax credits or equivalent cash payments for incremental R. & D. in chemicals and capital goods industries. [32]
14. Provide a graduated income tax rate structure to benefit new, technology-based firms. [32]
15. Apply small business tax rate (22 percent) to first $1 million of income rather than to first $25,000. [31]
16. Eliminate or reduce corporate tax on dividends paid out. [32]
17. Allow tax credits of up to 50 percent of costs of issuing common and preferred stock or nonconvertible debt issues. [9]
18. Exclude from taxable income decreasing percentages of revenues attributable to the sale of innovative products or licenses. [9]
19. Defer from taxation for 3 years revenues attributable to the sale of innovative products or licenses. [9]
20. Permit acquisition costs of technological innovation to be expensed rather than capitalized (change IRC, sec. 174). [9]
21. Permit multinationals to expense domestic costs of development of new products and processes in the place incurred (change IRC, secs. 861–864). [9]
22. Treat corporate cash dividends as deductible expenses for small firms. [9]
23. Create a variable investment tax credit with the rate and duration of credit linked to investment in technological innovation. [9]
24. Increase maximum asset value of "1244 stock" to $1 million, and increase loss allowance to $50,000 on individual and to $100,000 on joint returns (change IRC, sec. 1244). [9]
25. Employ tax incentives to promote intraindustry joint ventures for R. & D. [9]
26. Simplify tax reporting requirements for small firms. [31]
27. Increase efforts to inform firms of existing incentives for R. & D./I. [41]
28. The Experimental Technology Incentives Program (ETIP) should conduct studies and experiments to examine impact of tax incentives on innovation. [32]
29. Acquaint the appropriate employees of the Internal Revenue Service (IRS), the Small Business Administration (SBA), and Department of Commerce with the unique tax problems of small, technology-based firms. [41]

30. Explore the feasibility of industry sector-specific fiscal incentives for innovation, targeting start-up costs. [1]
31. Provide more generous capital gains tax treatment for new, technology-based firms. [32]
32. Provide special tax credit for private investment in all R. & D. leading to successful innovation. [3]
33. Reduce capital gains tax rates for direct investment in small, technology-based firms. [1, 31]

VENTURE CAPITAL

34. Relax limits on rates of sale of "restricted securities" to increase liquidity of venture capitalists' portfolios and of markets for individual firms' securities (change Securities and Exchange Commission (SEC) rule 144. [5, 9, 31, 32]
35. Allow unlimited sale of "restricted securities" after a 5-year holding period. [9]
36. Allow corporations, estates, and trusts to invest in subchapter S corporations and to receive benefits of 1244 stock. [31, 32]
37. Make investments in new, technologically based firms by individuals, institutions, or corporations tax deductible until the investments are sold. [31, 32]
38. Increase ceiling on regulation A offerings to $1 million. [9, 31]
39. Allow original investors in specified equity securities to deduct from ordinary income up to one-third the cost of the issue. [9]
40. Decrease bank reserve requirements in proportion to the amount of funds they lend innovative firms. [9]
41. Create in each Federal Reserve District a capital bank to provide venture capital to new, growing innovative firms. [20]
42. Increase Federal Reserve bank loan reserves for loans to finance innovation. [9]
43. Guarantee some portion (up to 50 percent) of loans granted by Small Business Investment Corporations (SBIC's) or other financial institutions to new technology-based firms. [32]
44. Reduce cost of compliance with disclosure requirements for small firms (change SEC rule 146). [9]
45. Guarantee (up to 80 percent) loans to cover costs of registration of stock offerings intended to finance innovation. [9]
46. Establish an indemnity or insurance fund to reimburse qualifying technology-based firms for legal expenses incurred in actions related to antifraud provisions of securities acts. [9]
47. Form a National Venture Development Program (NVDP) to coordinate public policies to encourage formation of venture capital. [1]
48. Provide Federal financing of additional seed capital through quasi-public agencies. [1, 5]
49. Allow "good will" to be written off in merger accounting before tax rather than after tax. [32]
50. Transfer administration of funds for entrepreneurs from the National Science Foundation's Research Applied to National Needs program (NSF/RANN) to the National Technical Information Service (NTIS) in the Department of Commerce. [32]
51. Departments of Commerce and Treasury and the SEC should conduct forums for major investment institutions to discuss potential and problems of venture capital formation. [32]
52. Develop mechanisms to furnish information on venture capital to new, small firms at regional levels. [5, 41]
53. Mandate the Department of Commerce to serve as Federal spokesman and representative for new, technology-based firms, and to work especially with problems of venture capital availability. [41]
54. Department of Commerce should broaden its studies of the innovative and entrepreneurial processes and their relation to venture capital. [41]
55. Establish a Federal Innovation Insurance Corporation (FIIC) to insure approved innovation investments against losses. [5, 9]

56. Provide government insurance for innovating firms with a technologically successful project against financial failure due to unforeseen market problems. [9]
57. Revive the SBA innovation loan program that was operative from 1967 to 1970. [5, 9]
58. Provide Federal subsidies for interest on long-term loans to small firms for innovation. [9]
59. Allow government institutions to issue long-term unsecured loans to small firms unable to receive bank loans, guaranteed up to 80 percent of the outstanding principal. [9]
60. Provide an innovating firm a guaranteed return on specified innovations through deficiency payments in the event the market price is lower than expected; such payments would be treated as loans repayable by the firm in 3–5 years. [9]
61. Guarantee loans used to finance acquisition of one company by another for purposes of innovation. [9]
62. Provide Federal credit insurance to private venture capitalists, financed by premiums and fees. [39]
63. Issue government-funded interest-free or low-interest loans directly to qualified innovating firms. [3, 5]
64. Guarantee loans for the acquisition of productivity-improving technology, i.e., stimulate process rather than product innovation. [5]
65. Amend Investment Company Act of 1940 to enhance climate for venture capital firms. [5]
66. Review the SBIC program in innovation to determine why it failed. [5]
67. Develop curricula in venture capital management in universities and professional schools. [5]

FOREIGN TRADE

68. Establish a board within the Executive branch to develop policies for control of exports of U.S. technology. [32]
69. Develop an international trade strategy that exports technology embedded in products rather than "naked" technological knowledge in the form of licenses and blueprints. [3, 32]
70. Negotiate a shortened International Control Coordinating Committee List, and an efficient means of keeping it updated. [32]
71. Assist firms specializing in military products to shift to civilian products and thereby to achieve expanded export levels, using improved market identification, better Federal promotional activities, and exposure of foreign protective practices. [32]
72. Simplify licensing procedures of the Departments of State, Commerce, Energy, and the Nuclear Regulatory Commission (NRC) to lessen delays encountered by exporters. [32]
73. Strengthen the financial policies of the Export-Import Bank. [32]
74. Require the Export-Import Bank to give preferential treatment to qualifying innovation industries to promote exports. [9]
75. Require the Department of Defense to identify areas of commercial technology to exclude from export to adversary nations. [32]
76. Establish within the Department of Commerce a capacity to analyze technological developments in non-Communist nations to assess what exported technologies (especially military) should be controlled. [32]
77. Remove all controls on export of U.S. commercial technology. [18, 22]
78. Develop a Federal policy and a "code of behavior" for multinationals to contribute to the technological development of less-developed countries (LDC's). [18, 32]
79. Aid LDC's in developing regional institutions for R. & D. [18]
80. Develop a coordinated program in Organization for Economic Cooperation and Development (OECD) for the selective transfer of technologies owned by OECD members to LDC's. [18]
81. Develop unified OECD policy governing technology transfer to the U.S.S.R. [18]
82. Develop increased R. & D. cooperation among OECD nations in specific areas (computers, urban development, marine resources, environmental protection). [23]

83. Study technology transfer among OECD members. [18]
84. Develop and maintain inventories of inventions owned by the Federal Government that could be transferred to LDC's. [18]
85. Study U.S. deficiencies in international standards, and prepare policies to alleviate them. [32]
86. Support title II (international standards) of the Voluntary Standards and Accreditation Act of 1977 (H.R. 8184, S. 825). [32]
87. Reduce nontariff barriers to trade, e.g., safety requirements, verification procedures, quality standards. [23]

FEDERAL R. & D.

88. Repeal the "Mansfield Amendment" if study by Office of Science and Technology Policy (OSTP) indicates that increased mission oriented research has detracted from basic research. [32]
89. Fund engineering and applied science education, but not commercial R. & D. [18]
90. Increase university R. & D. by government contracts, or tax credits for private firms contracting work with universities. [4]
91. Encourage universities to engage in more applied research. [17, 20]
92. Create a publicly funded, profit oriented National R. & D. Corporation to buy research or patents, demonstrate their commercial feasibility, and then sell them back to private firms for commercialization. [4]
93. Create a National Institute of Technology (NIT) to provide grants to private firms for research falling between basic and product research, and to demonstrate the feasibility of advanced designs. [21]
94. Encourage large Federal research institutions to market their new technologies to other Federal agencies and to institutions in the private sector. [34]
95. Categorize all Federal R. & D. expenditures into three functional areas: Basic research, mission oriented research, and massive mobilization research. [30]
96. Ignore potential "spinoffs" and economic multipliers in allocating R. & D. expenditures. [30]
97. Continue public R. & D. funding for longer time periods in nonmilitary and nonmedical areas to bring the technology to greater development before expecting private firms to take over. [30]
98. Allow for "institutional constraints" and bureaucratic exigencies while designing public R. & D. programs. [30]
99. Develop clearer guidelines for determining how long public funds should be used in commercializing new technologies. [30]
100. Develop more effective channels to enable Congress to review Department of Defense R. & D. expenditures. [30]
101. Employ a continuous, systematic audit of all Federal R. & D. to determine its impact on various sectors of the economy, and to propose changes to make it more effective. [17, 30]
102. Consolidate all existing field demonstration programs of various Federal agencies under Department of Commerce control. [32]
103. Use following criteria to guide deployment of public R. & D. funds in the private sector:

(*a*) Encourage industrial research in areas with small, short-term economic rewards, yet potentially large social rewards. [32]

(*b*) Encourage cost reduction R. & D. rather than new product R. & D. [30]

(*c*) Encourage small, flexible projects, not large-scale efforts, in only the earliest stages of development [7, 8, 30]

(*d*) Encourage industries lacking strong internal R. & D. capacity, where institutional barriers hinder R. & D., or where rapid technological progress would be likely. [5, 21]

(*e*) Encourage civilian R. & D. rather than military or space R. & D. [8]

(*f*) Couple R. & D. with market demand rather than with technology push. [8]

(*g*) Encourage high levels of nonmission oriented research. [10]

(*h*) Encourage mission oriented research in specific sectors with demonstration projects. [20]

(*i*) Include as objectives aesthetic, work satisfaction, environmental, and other social factors. [7]

104. Expand federally funded R. & D. by establishing more federally owned and operated research centers. [4, 8]
105. Expand federally funded R. & D. by supporting nonprofit private research organizations. [4]
106. Expand federally funded R. & D. by contracting or cost sharing with small innovative firms or entrepreneurs. [4]
107. Expand federally funded R. & D. by contracting with firms having excess R. & D. facilities due to cut-backs in defense or space R. & D. [4]
108. Expand federally funded R. & D. by contracting with manufacturers of capital goods. [4]

ECONOMIC REGULATION

109. Rationalize local, State, and Federal regulatory standards. [1, 5]
110. Expand prelegislative and preregulatory cost/benefit analyses to determine impact of proposed regulatory measures on industrial risk-taking ability and innovative performance. [1, 18, 22, 32, 39]
111. Establish a permanent group in the Department of Commerce to assess the impact of economic regulation on technological innovation. [32]
112. Establish a corps of technology advisers responsible to an external technology office to work in regulatory agencies. [39]
113. Establish a group in the Executive Office to promote the President's policies regarding innovation in the regulatory agencies. [39]
114. Require all regulatory agencies to analyze in annual "technology impact reports" how they affect innovation. [39]
115. Establish advisory panels in the National Academy of Science (NAS) or National Academy of Engineering (NAE) to advise regulatory agencies on technological matters. [39]
116. Revamp or eliminate obsolete regulatory agencies established in response to problems that are no longer of primary importance. [29]
117. Conduct forums to exchange industry and government views on regulatory impacts on innovation. [1]
118. Upgrade professional staffs of regulatory agencies to improve their ability to set and monitor standards. [1]

ENVIRONMENTAL, HEALTH, SAFETY, AND CONSUMER REGULATION

119. Establish a "science court" to provide for direct adversary argumentation in front of impartial experts on scientific issues relating to regulation. [32]
120. Utilize existing institutions to sensitize and train scientists to maintain integrity and objectivity as "expert witnesses" on controversial issues. [32]
121. Simplify the documentation and reporting required by regulatory agencies. [18]
122. Employ performance rather than design objectives for environmental and safety regulations. [18]
123. Place customs duties on foreign goods not subject to the same burden of environmental and safety standards to account for the full "social costs" of the use of the goods. [1, 18]
124. Provide Federal subsidies for interest on loans for the additional cost of compliance with environmental and safety regulations in innovation. [9]
125. Allow expense carry-back of legal, accounting, or administrative costs in innovation in complying with environmental or safety regulations. [9]
126. Establish a permanent group in the Department of Commerce to assess the impact of environmental, health, safety, and consumer regulation on technological innovation. [5, 32]
127. Develop publicly funded technological institutes to define political and economic trade-offs for government-imposed environmental, health, safety, and consumer standards. [25]

128. Support title I (national standards) of the Voluntary Standards and Accreditation Act of 1977 (H.R. 8184, S. 825), but modify the rigorous regulatory framework set by the bill so that future product standards needs are identified jointly with the private sector. [32]

ANTITRUST POLICY

129. Repeal antitrust exemptions of the railroad and trucking rate bureaus. [9]
130. Relax antitrust laws to permit firms within an industry to create joint ventures in certain basic researches, the results of which would be shared among the firms. [9, 18]
131. Relax antitrust restrictions on R. & D. cooperation among small firms (but not large firms). [32]
132. Antitrust and regulatory agencies should provide guidelines clarifying the legality of business conduct regarding competition and innovation. [5, 41]
133. Study the effect of antitrust relaxation on cooperative R. & D. to determine whether relaxation would produce socially desired innovation. [1, 32]
134. Balance the stimulation of competition and innovation in the interpretation and administration of antitrust and regulatory laws. [41]
135. Strengthen the staffs of antitrust and regulatory agencies by increasing the number of employees who understand problems of R. & D./I. [41]
136. Develop advisory boards from the private sector or the Federal Government to advise antitrust and regulatory agencies on the past and expected impact of antitrust policy on innovation and invention. [1, 41]
137. Consider the interaction of technological change and competition in antitrust legislation. [41]

PATENT POLICY

138. Speed passage of the patent reform bill (1973) through Congress. [1]
139. Decrease cost of patent applications for amateur inventors and small firms. [1]
140. Department of Commerce should play leading role in developing a unified administration position on patent revision legislation (1977). [32]
141. Establish a federally regulated innovation cross-licensing pool. [9]
142. Develop an international patent system. [34]
143. Do not develop an international patent system since the current system (1973) works to the U.S.'s advantage vis-a-vis smaller, less inventive nations. [2]
144. Develop a dual patent system to provide long-term protection for expensive, major technological breakthroughs, and short-term protection for incremental inventive efforts. [42]
145. Standardize ownership policy for inventions resulting from all federally funded R. & D. [32]
146. Continue current (1977) NTIS program of alerting potential users to the existence of government-owned inventions. [32]
147. Fund the commercialization of selected government-owned inventions. [32]
148. Develop government patent program granting title to government only when (i) public health, safety, or welfare is involved, (ii) government has been the major developer of the invention, (iii) government regulation requires use of the invention, (iv) the contractor operates a Federal facility, or (v) the invention is developed for an explicitly public use. [34]
149. Grant exclusive license for government patents to private firms or negotiate other proprietary arrangements. [5]

LABOR AND MANPOWER

150. Provide financial, retraining, and reemployment assistance to workers displaced by technological change. [1, 18, 22, 27, 34]
151. Sponsor research and experimentation to improve working conditions as they are being modified by new technologies. [1]
152. Inform private and public decisionmakers of possible adverse effects of innovation on labor. [1]
153. OSTP should develop coordinated government policy to ensure a long-term supply of skilled science and technology manpower. [4, 32]

154. Study how skill and training requirements affect innovation. [39]
155. Do not use manpower training programs to facilitate diffusion of new technologies. [39]
156. Encourage mobility of scientists and engineers in and out of government laboratories. [17, 22]
157. Give labor increased participation in decisionmaking regarding innovation. [18]
158. Develop Federal policies to retrain Ph. D. engineers unable to find work in their area of expertise. [18]
159. Train engineers and others involved in innovation in up-to-date science to diminish the lag between discovery of new scientific knowledge and its technological application. [34]
160. Create new Civil Service designations and job descriptions to recognize the profession of technology-utilization agent. [5]

FEDERAL PROCUREMENT

161. Initiate an interdepartmental ad hoc review of contracting and procurement procedures among agencies including the Department of Defense, National Aeronautics and Space Administration and National Institutes of Health to ensure that the procedures are consistent and conducive to long-term growth of small firms. [41]
162. Develop performance standards rather than design standards, and use life cycle costing in Federal procurement. [1, 20, 21, 23]
163. Use Federal procurement to upgrade technical levels of specified industries or products, to couple technology more effectively to social needs, and to aid in diffusion of innovation. [9, 22, 32, 34]
164. Provide market security for specified innovations through procurement policies. [9]
165. Develop publicly funded technological institutes to formulate standards for Federal procurement. [25]
166. Provide prizes for individuals or groups in the Federal Government who stimulate innovation by their procurement methods. [2]
167. Aggregate public markets (local, State, Federal) by developing uniform procurement policies based on performance standards. [34]

INFORMATION DISSEMINATION, FURTHER STUDIES

168. Systematize efforts to inform general public of the consequences of major technological decisions and developments. [32]
169. Strengthen and enlarge the NTIS. [32]
170. Establish an Industrial Technology Extension Service to acquaint small firms and entrepreneurs with technological innovations and patents. [21, 32]
171. Expand the Department of Commerce's consumer information services. [32]
172. Establish a national center for the study of innovation. [34]
173. Disseminate more widely the results of publicly supported R. & D., and encourage the diffusion of the technology. [20]
174. Systematically collect data on the effect of all Federal policies on innovation. [27]
175. Establish a pilot cooperative (public-private) clearinghouse to provide market information to innovative firms. [1]

STATE AND LOCAL GOVERNMENT INNOVATION

176. OSTP should encourage transfer of federally developed technology to the State and local levels. [30, 32]
177. Provide categorical grants to States for use in assessing their resources and markets, in expressing their technological needs, and in working toward meeting them. [9, 32]

178. Allow State governments to issue bonds to raise funds for long-term loans to innovating firms. [9]
179. Help State procurement personnel develop performance rather than design standards. [39]
180. Encourage State and local governments to use revenue sharing funds to stimulate technological innovation in public works. [39]
181. Create an information clearinghouse to collect, organize, and disseminate information on technological innovation to State and local governments. [32]
182. Modify revenue sharing to give Federal agencies more discretionary power to urge State and local governments to use the funds to support innovation. [39]

CORPORATE ORGANIZATION FOR INNOVATION

183. Study internal corporate barriers and "people problems" in firms engaged in R. & D./I. [1]
184. Use systems analysis to integrate components of the R. & D./I process: basic science, research laboratories, manufacturing capacities, and management goals. [34]
185. Management should permit and promote opportunities for employees to act on ideas coming from outside established channels. [2]
186. Management should promote interdisciplinary R. & D./I. teams. [10]
187. Management should promote wide-ranging personal contacts between R. & D./I. workers. [10]
188. Management should promote strong horizontal links between functional departments and between development activities and eventual users of the technology. [25]

GENERAL

189. Hold a White House Conference and regional conferences on innovation and its barriers. [41]
190. Allocate more funds for private studies of productivity and innovation in industry-specific commercial technology, and of the impact of government policies on innovation. [3, 18, 25, 37].
191. Establish as a primary goal the stimulation of R. & D./I. in areas relevant to society's quality of life where market forces cannot assure optimal levels of effort. [3, 20]
192. Develop national science and technology policy around the primary goal of reducing uncertainty in R. & D./I. [29]
193. Develop national science and technology policy that is incremental, flexible, not oriented around large projects, and is demand-pulled rather than technology-pushed. [8]
194. Develop national science and technology policy that is consistent with other economic and social policies, and reinforces private market forces. [38]
195. Encourage studies in the history and sociology of science and technology to further understanding of the principles behind the variety of patterns of successful R. & D./I. and diffusion of technology. [17]
196. Use technological forecasting to identify new goals for applied research [17]
197. Increase trust between government and industry. [27]
198. Locate ETIP more strategically within the executive branch to increase its power (1975). [8]
199. Increase capacity within the Federal Government for microeconomic policy analysis. [8]
200. Develop more rational and systematic policies to promote science and technology. [29]
201. Require "research impact statements" from all Federal agencies planning major policy changes. [8]
202. Include material on innovation in university and professional school curricula for managerial and business students. [5, 34]
203. Consumer groups should specify desired performance standards for goods to induce market-directed R. & D./I. in consumer areas. [7]

204. Make technology utilization a line item in Federal agency budgets. [5]
205. Develop and refine within the Federal Government tools to improve the identification of high potential technology, market research, and user need analysis. [5]

TABLE 1.—*Total Number of Policy Recommendations for Stimulating Innovation*

1. Taxation	33
2. Venture capital	34
3. Foreign trade	20
4. Federal R. & D	21
5. Economic regulation	10
6. Environmental, health, safety, and consumer regulation	10
7. Antitrust policy	9
8. Patent policy	12
9. Labor and manpower	11
10. Federal procurement	7
11. Information dissemination, further studies	8
12. State/local government innovation	7
13. Corporate organization for innovation	6
14. General	17
Total	205

II. ACTION PARTIES IN POLICY RECOMMENDATIONS FOR STIMULATING INNOVATION

Table 2, which follows, lists in abbreviated form the 205 policy recommendations extracted from the 42 studies included in this collection, and identifies three types of action parties related to each recommendation. The intent of Table 2 is to portray a sense of the policy-execution-impact nexis, and not to provide precise information. The identification of action parties, their degree of specificity, and their determination for each of the recommendations represent the combined "best informed guesses" of five science and technology policy analysts from the Congressional Research Service. We have not attempted to locate with great precision or detail, the exact offices or divisions within the vast Federal bureaucracy which might become action parties for the recommendations. The reader is invited to alter or add to the entries in the matrix.

For each recommendation, three types of action parties have been specified. The *policymaker* (P) would have direct authority or jurisdiction for making the policy suggested by the recommendation. The *executor of policy* (E) would carry out the policy once it had been determined. The *impacted party* (I) would be directly affected by the executed policy. For most recommendations, the policymakers and executors are in the public sector, and the impacted parties are in the private sector. A solid dark line in Table 2 separates the public and private actors. The same party may have both policy and execution responsibility. For some recommendations (eg., for further studies), no directly impacted party may exist.

Only the primary or most directly involved action parties have been identified, since indirectly, nearly every actor would be involved in every recommendation, given the interconnectedness of policymaking and execution. Likewise, wherever possible, the narrowest specification of an action party has been noted. For example, if the execution of a policy would involve only the Internal Revenue Service, only the IRS and not the more inclusive Treasury Department has been indicated. See the key following Table 2 for more complete descriptions of the action parties as listed in the Table. Likewise, the reader may wish to refer back to section I of this chapter for fuller statements of the individual recommendations.

TABLE 2. ACTION PARTIES IN POLICY RECOMMENDATIONS FOR STIMULATING INNOVATION

P = Policymaker

E = Executor of policy

I = Impacted party

Policy recommendation / Action party	CONGRESS	GAO	EXECUTIVE BRANCH	President's Office	OSTP	OMB	Departments	Commerce	NTIS	NBS	ETIP	PTO	Treasury	IRS	Justice	Antitrust division	Labor	State	Defense	Environmental, health, safety, consumer regulatory agencies	Economic regulatory agencies	FTC	SEC	U.S. International Trade Commission	Federal R & D agencies (NASA, HEW, DOE, etc)	Independent agencies	Federal Reserve Bd	Export-Import Bank	SBA	NSF	New agencies	STATE/LOCAL GOVERNMENTS	UNIVERSITIES	NAS, NAE, NRC	BANKS, INVESTMENT INSTITUTIONS	INDUSTRY	Small firms	LABOR	SCIENTISTS, ENGINEERS, INVENTORS	NOT FOR PROFIT ORGANIZATIONS	GENERAL PUBLIC
TAXATION																																									
1. Extend loss carry-over to 10 years	P												E																								I				
2. Liberalize qualified stock option rules	P																					E														I				
3. Relax R & D deduction criteria for inventors	P												E																									I		
4. Extend inventor write-off of earlier R & D costs	P												E																									I		
5. Capital gains break for professional inventor	P												E																									I		
6. Allow unrelated R & D write-offs	P												E																					I					
7. Increase write-offs for technology purchases	P												E																					I					
8. Increase tax credit for R & D plant	P												E																					I					
9. Increase tax depreciation allowance for R & D plant	P												E																					I					
10. Replace R & D plant tax credit with R & D expenditure credit	P												E																					I					
11. New tax credits for industrial R & D	P												E																					I					
12. New tax credits for incremental R & D	P												E																					I					
13. New tax credits for incremental R & D in chemicals and capital goods	P												E																					I					
14. Graduated corporate income tax for new, technology-based firms	P												E																					I					

15. Increase base for small business tax rate	P													E																							I				
16. Reduce corporate tax on dividends paid	P													E																						I					
17. Tax credit for equity borrowing costs	P													E									E													I					
18. Tax deduction for revenues from innovation	P													E																						I			I		
19. Tax deferral for revenues from innovation	P													E																						I			I		
20. Expense acquisition cost of technological innovation	P													E																						I					
21. Expense domestic costs of new product development	P													E																						I					
22. Treat corporate cash dividend as deductible expense	P													E																							I				
23. Provide a variable investment tax credit	P													E																						I					
24. Increase ceilings on small business investment losses	P													E																						I					I
25. Tax incentives to promote innovation joint ventures	P													E		E																				I					
26. Simplify tax reporting for small firms														P E																							I				
27. Inform firms of existing tax incentives for R & D/I														P E																						I			I		
28. ETIP study of impact of tax incentives on R & D/I					P			P			E																									I					
29. Inform tax agency staff of tax problems of small firms					P			E						E															E								I				
30. Explore industry sector-specific fiscal incentives	P							E																					E	E			E			I					
31. Liberalize capital gains treatment for new firms	P													E																						I					
32. Tax credits for successful R & D/I	P													E																						I					
33. Reduce capital gains tax for investment in small firms	P													E																							I				
VENTURE CAPITAL																																									
34. Increase SEC Rule 144 limitation on rate of sale																							P E												I	I					

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35. Remove limit on sale of restricted securities																							P E													I					
36. Expand access to Subchapter S corporations and 1244 stock																							P E														I				
37. Allow deduction of investments in new technology firms until sold	P													E																					I	I					
38. Raise ceiling on Regulation A offerings																							P E													I					
39. Tax deduction for cost of issue	P													E																					I						I
40. Decrease bank reserve requirement in proportion to innovation loans																											P E								I	I					
41. Create capital banks for venture capital	P																										E									I					
42. Increase bank loan reserves for innovation loans																											P E								I	I					
43. Guarantee loans for innovation	P																												E						I	I					
44. Less stringent disclosure for SEC Rule 146																											P E										I				
45. Loan guarantees for registration costs	P																						E						E						I	I					
46. Establish insurance or indemnity fund for antifraud legal expense	P												E		E								E													I					
47. Form National Venture Development Program	P												E																E		E				I	I			I		
48. Create quasi-public agencies for seed capital	P					E																									E				E	I			I	I	

49. Merger accounting write-offs before tax	P													E																						I					
50. Transfer entrepreneurial funds from RANN to NTIS	P			P					E I																					E I											
51. Forums on venture capital formation					P			E					E										E												I						
52. Provide venture capital information to new firms				P				P E																					E			E					I				
53. Designate Commerce as spokesman for technology firms	P			P				E					I																I								I				
54. Commerce should study relation of venture capital and innovation				P				E																																	
55. Create Federal Innovation Insurance Corporation	P												E																		E				I		I				
56. Market insurance for innovators	P												E									E													I	I					
57. Revive SBA innovation loan program	P																												E								I				
58. Interest subsidy for small firms	P				P						E																		E								I				
59. Loan guarantees for small firms	P												E														E		E								I				
60. Price protection on specified innovations	P							E																					E		E					I					
61. Innovation acquisition loan guarantees	P							E					E													E					E				I	I					
62. Federal credit insurance for venture capitalists	P							E					E													E									I						
63. Government loans for innovation	P												E													E										I					
64. Guarantee loans for process innovation	P							E					E													E									I	I					
65. Amend Investment Company Act of 1940	P							E																					E						I						
66. Determine why SBIC innovation program failed	P			P																									P E												
67. Develop curricula in venture capital management					P																									P E			P E		I						
FOREIGN TRADE																																									
68. Export control board within Executive branch	P			E																											E						I				

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69. Export products and not "naked" technological know-how	P			P				E										E	E					E												I					
70. Shorten International Control Coordinating Committee list	P							E										E	E																	I					
71. Aid firms shifting from military to civilian products				P				E											E																	I					
72. Simplify licensing procedures for exporters				P		P		E										E						E												I					
73. Strengthen Export-Import Bank	P			P																								E								I					
74. Preferrential loan treatment for innovation exporters	P			P																								E								I					
75. Control exports to adversary nations	P			P		P		E											E																	I					
76. Examine export controls on non-communist nations				P		P		E																												I					
77. Decontrol all commercial exports	P							E										E	E																	I					
78. Multinational corporation aid in technological development of LDC's	P			P				E																E												I					
79. Regional R & D institutions for LDC's	P																	E												E											
80. Selective transfer of OECD technology to LDC's					P				E									E												E						I					
81. Unify OECD policy for technology transfer to the USSR					P													P E	E																						
82. Increased R & D cooperation in OECD					P			E										P E																		I					

83. Study technology transfer in OECD					P			E										P E																							
84. List Federal inventions available for LDC's					P				E			E						E							E																
85. Study U.S. deficiencies in international standards	P				P			P		E										E																I					
86. Support Title II of Voluntary Standards Act (1977)	P							E		E												E									E					I					
87. Reduce non-tariff barriers to trade	P			P			E													E																I					
FEDERAL R & D																																									
88. Repeal the "Mansfield Amendment"	P				E														E														I								
89. Increase funding for applied science education	P				P																									P E			I						I		
90. Increase university R & D through contracts or tax credits	P				P		E							E											E								I			I					
91. Increase applied research in universities					P																									E			I								
92. Create publicly funded National R & D Corporation	P											E													E						E					I					
93. Create National Institute of Technology	P				P			E																							E					I					
94. Encourage marketing of federally-owned technology					P		E																		E					E						I					
95. New categorization of Federal R & D					P	P		E																	E					E											
96. Ignore "spinoffs" in allocating public R & D	P E					P E	P E																		I																
97. Fund public R & D longer into the development stage	P					P	E																		E					E						I					
98. Allow for bureaucratic exigencies in R & D design	P E				P E	P E		E																	E					E											
99. Develop criteria for public commercialization of innovation	P				P			E																	E					E											
100. Enable more extensive congressional review of DoD R & D	P																		E																						
101. Continuous audit of impact of Federal R & D	P	P E				E																			I					I											
102. Consolidate control of all demonstration programs in Commerce	P							E																																	

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103. Develop criteria for use of public R & D	P				E																				E											I					
104. Establish federally-owned research centers	P				P		E																		E																
105. Expand public support for non-profit private R & D	P				P																				E					E										I	
106. Expand Federal R & D contracts with small firms	P				P																				E					E							I				
107. Use excess defense R & D facilities for civilian R & D	P				P														E						E											I					
108. Expand Federal R & D with capital goods manufacturers	P				P		E																													I					
ECONOMIC REGULATION																																									
109. Rationalize all levels of regulatory standards	P							P E												E	E											E				I					
110. Cost/benefit analysis of regulatory standards	P	E			P	E														E	E															I					
111. Review impact of regulation on innovation								P E													I																				
112. Technology advisors for regulatory agencies	P																			E	E										E					I			I		
113. Innovation spokesman in Executive Office				P E																I	I										E										
114. Annual "technology impact reports" from regulatory agencies	P																			E	E																				
115. NAS/NAE advisory panels for regulatory agencies																				I	I													P E							
116. Eliminate obsolete regulatory agencies	P			E																I	I																				

117. Forums on impact of regulation on innovation					P			E													E									E						I					
118. Upgrade professional staffs of regulatory agencies				P		P														E	E															I					
ENVIRONMENTAL, HEALTH, SAFETY REGULATION																																									
119. Establish a "science court"				P																E I											E								E I		
120. Train scientists as "expert witnesses"																														P E			P E						I		
121. Simplify reporting requirements of regulatory agencies	P			P																E	E															I				I	
122. Use performance standards in regulations	P				P															E																I				I	
123. Levy customs duty for full "social costs"	P												E																							I					
124. Subsidize interest rates for regulation compliance costs	P					P		E					E							E																I					
125. Allow expense carry-back of legal costs for compliance	P													E						E																I					
126. Commerce should assess impact of regulation on innovation	P			P				E												E																					
127. Public technology institutes to define product standards	P																			I											E			E							
128. Support Title I of Voluntary Standards Act (1977)	P									E												E														I					
ANTITRUST POLICY																																									
129. Repeal antitrust exemptions of transport rate bureaus	P															E					E															I					
130. Permit more joint ventures in basic research	P															E																				I					
131. Permit more R & D cooperation among small firms	P															E																					I				
132. Clarify antitrust guidelines				P												E					E															I					
133. Study effect of relaxation of antitrust laws					P			E								E																	P E	P E		I					
134. Consider innovation while administering antitrust laws				P				E								E				E	E															I					
135. Increase antitrust agency staff's understanding of innovation						P										E				E	E															I			I		
136. Innovation advisory boards for antitrust agencies					P											E				E	E															I			I		

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137. Consider innovation while developing antitrust legislation	P			P												E				E	E															I			I		
PATENT POLICY																																									
138. Enact patent reform bill (1973)	P											E																								I			I		
139. Decrease patent application costs	P											P E																									I		I		
140. Develop unified administration position on patent reform (1977)				P				E																												I			I		
141. Establish regulated cross-licensing pool	P											E																								I			I		
142. Develop international patent system	P				P							E						E																		I					
143. Do not develop international patent system	P				P							E						E																		I					
144. Develop a dual patent system	P											E																								I			I		
145. Standardize government patent ownership policy	P			P								E													E											I			I		
146. Alert potential users of government patents								P	E																											I					
147. Commercialize selected government inventions	P					P					E														E											I			I		
148. Develop criteria specifying government patent ownership	P					P						E													E											I					
149. Grant licenses for government patents to private firms	P					P						E													E											I			I		
LABOR AND MANPOWER																																									
150. Provide assistance for displaced workers	P																E																			I		I	I		

151. Improve working conditions associated with new technologies	P					P											E																			I		I	I		
152. Inform decisionmakers of effect of innovations on labor																	P E																			I		I			
153. Ensure continued supply of skilled S & T manpower				P	E												E																					I	I		
154. Study relation of manpower skills and innovation					P												E													E			E					I			
155. Do not attempt to diffuse technology through manpower training	P																E																			I					
156. Encourage mobility of scientists and engineers	P					P											E								E								E						I		
157. Increase participation of labor in decisionmaking	P			P													E																			P		I			
158. Retrain unemployed PhD engineers					P																									E									I		
159. Teach innovators and engineers the most up-to-date science					P																									P E			P E			I			I		
160. Create Civil Service job title of technology-utilization agent				P																						E															
FEDERAL PROCUREMENT																																									
161. Review all agency procurement procedures for consistency				P		E	E																		E											I					
162. Use performance standards and life cycle costing in procurement						P	E													E					E											I					
163. Use procurement to stimulate specified industries					P	P	E													E					E											I					
164. Use procurement to provide market guarantees					P	P	E													E					E											I					
165. Create technological institutes to set procurement standards	P					I	I																								E					I					
166. Prizes for procurement officials who stimulate innovation				P		P	E																								E					I					
167. Aggregate public markets	P					P	P																									E				I					
INFORMATION DISSEMINATION, FURTHER STUDIES																																									
168. Inform public of impacts of technology	P			P				P E	E																																I
169. Strengthen NTIS					P			P E	E																											I			I		
170. Establish an Industrial Technology Extension Service	P							E																							E						I		I		

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171. Expand Commerce's consumer information service					P			E																																	I
172. Establish a national center for study of innovation					P			E																							E										
173. Widely disseminate the results of public R & D	P					P			E																E											I			I		
174. Study impact of Federal policies on innovation	P			P				E																						E											
175. Create a market information clearinghouse for innovators					P			E			E																									I					
STATE AND LOCAL GOVERNMENT INNOVATION																																									
176. Transfer Federal technology to state and local levels	P				P		E																		E							I									
177. Federal-State market and resource assessment	P							E																								I									
178. State technology investment bonds	P												E																			E				I					
179. State and local procurement performance standards					P						E																			E		I									
180. Revenue sharing funds for innovation	P				P																											E				I					
181. State and local information clearinghouse on innovation					P			P E																								I									
182. Increase Federal control over revenue sharing for innovation	P						E																									I									
CORPORATE ORGANIZATION FOR INNOVATION																																									
183. Study internal corporate barriers to innovation					P			E																						E						E I					
184. Use systems analysis to integrate R & D/I processes								P E																	P E											P E					

185. Reduce "Not Invented Here" syndrome								P																												P E			I		
186. Interdisciplinary R & D/I teams								P																												P E			I		
187. Increase personal contact among R & D/I workers								P																												P E			I		
188. Link R & D departments and eventual users of the innovations								P																												P E			I		
GENERAL																																									
189. White House Conference on innovation				P				E																								E	E			I			I	I	I
190. Private studies of productivity and innovation	P					P																								E			I	I						I	
191. Stimulate R & D/I to improve quality of life	P						E																													I					I
192. Reduce uncertainty in R & D/I	P						E																		E											I					
193. Develop incremental, flexible, demand pushed S & T policy	P						E																		E											I					
194. Integrate S & T policy with social and economic policy	P						E																		E											I					
195. Study history and sociology of S & T					P																									P E			E	E		I					
196. Employ technological forecasting	P				P																									E						I					
197. Increase government-industry trust	P			P			E																													E					
198. Relocate ETIP	P			P			E				E																														
199. Improve federal micro-economic analysis	P			P		P	E																							E											
200. Develop more rational and systematic S & T policy	P				P E		E																													I					
201. "Research impact statements" from all Federal agencies	P			P			E													E					E	E															
202. Improve university curricula on innovation					P																									P			P E			I			I		
203. Consumer groups should specify performance standards																																				I				E	P E
204. Make technology use a line item in Federal budgets	P					E	I																		I	I															
205. Improve Federal tools for market research	P				P		E																							E						I					

Addendum to Table 2

A key to the action parties as listed in Table 2:

Congress: Includes congressional members committees staffs.

GAO: General Accounting Office, assists Congress in carrying out its legislative and oversight responsibilities.

Executive Branch: Includes all executive branch institutions.

President's Office: The White House Office, within the Executive Office of the President.

OSTP: Office of Science and Technology Policy, within the Executive Office of the President.

OMB: Office of Management and Budget, within the Executive Office of the President.

Departments: Includes all twelve departments of the executive branch.

Commerce: Department of Commerce.

NTIS: National Technical Information Service, under the Assistant Secretary for Science and Technology within Commerce.

NBS: National Bureau of Standards, under the Assistant Secretary for Science and Technology within Commerce.

ETIP: Experimental Technology Incentives Program, under the Assistant Secretary for Science and Technology within Commerce.

PTO: Patent and Trademark Office, under the Assistant Secretary for Science and Technology within Commerce.

Treasury: Department of the Treasury.

IRS: Internal Revenue Service, within Treasury.

Justice: Department of Justice.

Antitrust Division: Within Justice.

Labor: Department of Labor.

State: Department of State.

Defense: Department of Defense.

Environmental, health, safety, consumer regulatory agencies: Includes all agencies or offices engaged in such regulation, such as the Council on Environmental Quality in the Executive Office of the President, the Occupational Safety and Health Administration within Labor, the Consumer Protection Safety Commission, Environmental Protection Agency (both independent agencies), and many smaller agencies located throughout the executive branch.

Economic regulatory agencies: Includes, in addition to the FTC, SEC, and ITC (which are listed separately), other economic regulatory agencies like the Economic Regulatory Administration and the Federal Energy Regulatory Commission within the Department of Energy, and the Interstate Commerce Commission and the Nuclear Regulatory Commission (independent agencies).

FTC: Federal Trade Commission, an independent agency.

SEC: Securities and Exchange Commission, an independent agency.

U.S. International Trade Commission: An independent agency.

Federal R. & D. agencies: Includes all agencies significantly engaged in R. & D., either "in house," or via contracts with private firms or universities, such as the Departments of Defense; Energy; Health, Education, and Welfare; NASA; NSF; etc.

Independent agencies: These agencies, of which there are many, exist by separate acts of Congress, and are organizationally distinct from the twelve departments of the executive branch.

Federal Reserve Board: Governs the Federal Reserve System, an independent agency.

Export-Import Bank: A public banking corporation which assists in financing trade, an independent agency.

SBA: Small Business Administration, an independent agency.

NSF: National Science Foundation, an independent agency.

New agencies: Indicated when recommendations might require the establishment of a program or organization currently not in existence.

State/local governments: Includes all relevant institutions at these levels of government.

Universities: Includes all universities and colleges engaged in significant amounts of basic and applied research.

NAS, NAE, NRC: National Academy of Sciences, National Academy of Engineering, National Research Council. Though not government agencies, these organizations of distinguished scientists and engineers work closely with Federal agencies in advising the formation of public science and technology policy.
Banks, investment institutions: Includes all private financial institutions which invest in R. & D./I.
Industry: Includes all firms engaged in R. & D./I.
Small firms: Includes only "small" technology-based firms.
Labor: Organized labor unions.
Scientists, engineers, inventors: Includes those most closely involved in the technical aspects of R. & D./I.
Not for profit organizations: Includes foundations and other not for profits which study or support R. & D./I.
General public: 220 million Americans.

III. Brief Abstracts of Two Decades of Innovation Studies

The following section lists the 42 studies selected for inclusion in this collection, and briefly describes the context of the research and the principal conclusions of each study. Call numbers are included for all those studies currently available through the Library of Congress. Most of the remaining studies are available from the National Technical Information Service, or the various contracting agencies.

Brief Abstracts of Two Decades of Innovation Studies

1. Arthur D. Little, Inc., and Industrial Research Institute, Inc. Barriers to innovation in industry; opportunities for public policy changes. Executive summary report. Prepared for the National Science Foundation under contracts NSF-C748 and C725. [Washington] 1973. 38 p.

   Based on interviews with industrialists, government officials, labor leaders, financial managers, and academicians, this A. D. Little, Inc., study concludes that the primary barriers to innovation are marketing (most important), finance, corporate organization, lack of venture capital, and government policies. It recommends clarifying public policy objectives (targeting specific industry sectors), and aggregating markets with government procurement.
2. Battelle-Columbus Laboratories. Science, technology, and innovation. Prepared for the National Science Foundation under contract NSF-C667. Columbus, Ohio, 1973. 33 p.

   A direct descendant of the TRACES (1968) study of the role of basic research in technological innovation, this study examines eight cases of successful innovation, and attempts to identify common factors such as need, opportunity, technical gatekeepers, or political exigencies. Seventy per cent of the "significant" events in the development of each innovation were found to be research events, evenly divided between nonmission- and mission-oriented research. But of significant events termed "decisive," only 15 per cent were nonmission. Hence, Battelle's study finds basic research playing a less crucial role in innovation than did TRACES.
3. Boretsky, Michael. Trends in U.S. technology; a political economist's view. American scientist v. 63, Jan.-Feb. 1975: 70-82. LJ85.S502.

   Boretsky argues that since 1965 the American rate of technological innovation has sharply declined, relative to growth rates in other industrial nations, and has been the primary cause of the deterioration of the U.S. trade position. He blames the decline in innovation on lower growth of investment in new industrial plant/equipment, underinvestment in R. & D., and especially on the one-sided diffusion of American technological knowledge through export of "naked" technology. Boretsky warns that unless these trends are reversed, the American economic and political position in the world will continue to slide.
4. ———. U.S. technology: trends and policy issues. Washington, The George Washington University Program of Policy Studies in Science and Technology, 1973. 174 p. (Monograph No. 17) T21.B67.

Boretsky outlines his policy suggestions to alleviate the innovation problem presented in the above-cited article. He calls for the formulation of a comprehensive national technology policy based on twelve "strategic elements" which include long-range planning, incentives for private R. & D. investment, and government procurement to stimulate diffusion of innovations.

5. Cunningham, Donald E., John R. Craig, and Theodore W. Schlie, eds. Technological innovation; the Experimental R. & D. Incentives Program. Boulder, Colo., Westview Press (1977). 505 p. T173.8.T4

This volume presents results from the first 3 years of the NSF Experimental Research and Development Incentives Program (RDI), and includes 26 papers (all done under NSF contracts) used for planning RDI programs. The papers treat various approaches to socioeconomic experimentation, technological innovation in private and public sectors, national government impacts on the innovation process, and provide numerous policy suggestions. An appendix provides abstracts of all RDI-contracted studies to date.

6. Denison, Edward F. Accounting for U.S. economic growth, 1929–69. Washington, The Brookings Institution (1974). 373 p. HC106.3.D3667.

In this pioneering econometrics study, Denison finds that changes in only seven of the many determinants of output were chiefly responsible for long-term growth and variations in the growth rate over a 40-year period. Of the seven key determinants, advance in knowledge (technological knowledge and managerial knowledge incorporated into the productive process) is identified as the most basic reason for persistent long-term growth of output per unit of input. Hence, Denison finds innovation as the most important producer of economic growth.

7. Freeman, Christopher. The economics of industrial innovation. (Baltimore) Penguin Books (1974). 409 p. HC79.T4F73.

This textbook provides a thorough review of current economic theories of innovation. Freeman argues that the professionalization of R. & D. has been one of the most important changes in modern industry, and that the requirements for successful innovation have greatly modified firm behavior by making world technology as well as world markets part of the firm's environment. Freeman concludes that market mechanisms have failed in consumer goods/services, and suggests greater public participation in consumer-oriented innovation.

8. Gilpin, Robert. Technology, economic growth, and international competitiveness. A report prepared for the use of the Subcommittee on Economic Growth of the Joint Economic Committee of the Congress of the United States. Washington, U.S. Government Printing Office, 1975. 87 p.

At head of title: 94th Congress, 1st session. Joint committee print. HC110.T4.G54.

Gilpin argues that a rejuvenation of civilian R. & D. and technological innovation is crucial to reverse the decline in American economic growth relative to other industrial nations. He examines falling expenditures for R. & D. over the past decade, presents arguments supporting public funding of R. & D., and compares the U.S. experience with Japan's and Britain's. Gilpin concludes that to revitalize innovation, Federal technology policy must be integrated with the broad range of government socioeconomic policies.

9. Harbridge House, Inc. Legal incentives to private investment in technological innovation. Preliminary final report. Prepared for the Office of Experimental R. & D. Incentives of the National Science Foundation under contract NSF–C893. n.p. [1975]. Various pagings.

This massive study presents 39 detailed policy suggestions for stimulating innovation, outlining precedents and pros/cons for the proposals, and ranking them in order of ease of implementation and economic leverage. Most of the incentives concern taxation, venture capital formation, and private sector investment. Nine Federal agencies also are examined with particular focus on the agencies' ability and authority to implement incentives for innovation.

10. Illinois Institute of Technology Research Institute. Technology in retrospect and critical events in science ["TRACES"]. Prepared for the National Science Foundation under contract NSF–C535. n.p., 1968. 118 p.

This classic study examines the role of basic scientific research in technological innovation. It identifies key events that led to five major technological

breakthroughs (birth control pills, electron microscopes, videotape recording, ceramic metallic materials, matrix isolation), and finds that 70 percent of them involved nonmission-oriented (basic) research. Yet often lag times of 20–30 years separated basic research from its application in innovations.

11. Isenson, Raymond S. Project hindsight; final report. Washington, Office of the Director of Defense Research and Engineering, 1969. 218 p. [Available from National Technical Information Service, AD 495 905].

Department of Defense analysts studied how new scientific and technological knowledge was applied in 20 recent military innovations (weapons systems and equipment). They found that over 85 percent of the new knowledge utilized had resulted from Department of Defense financed programs of mission-oriented research. They concluded that basic research is relatively unimportant in military technology innovation, except for the role it plays in the undergraduate education of engineers and scientists who later perform applied research.

12. Jewkes, John, David Sawers, and Richard Stillerman. The sources of invention. 2d ed. [London] Macmillan [1969]. 372 p. T212.J4 1969.

The authors studied 56 inventions made in the United States and United Kingdom over the past century. They found no sharp discontinuities in the occurrence of invention, that the time lag between invention and successful commercialization is not decreasing, and that the process of invention is becoming progressively institutionalized in firms, universities, or research institutions. They concluded that the patent system retards invention by granting too extensive monopolies, and that progressive rates of taxation hinder the individual inventor.

13. Kelly, Patrick, and Melvin Kranzberg, eds. Technological innovation; a critical review of current knowledge. San Francisco, San Francisco Press, Inc. [1978]. 408 p.

Written by an interdisciplinary team of the Georgia Tech Innovation Project, this study attempts to present a holistic view of innovation and to evaluate critically current knowledge of innovation. For conceptualization, they divide the innovative context into "indigenous" (problem definition, production, diffusion) and "exogenous" factors (human values, institutions). The volume also includes commissioned papers by Hughes, Mansfield, Kuznets, and others on technological forecasting, diffusion, historical case studies of important inventors, and state of the art reviews of economic and behavioral issues.

14. Langrish, J., and others. Wealth from knowledge. A study of innovation in industry. New York, John Wiley [1972]. 490 p. T173.5.G7W4 1972.

These researchers from the University of Manchester studied the 84 innovations winning Queen's Awards in the U.K. in 1966–67. They found that the most important factor ensuring the success of an innovation was an outstanding technical manager, that weak markets were most important in delaying innovation, that demand pull was more important than discovery push, and that many of the crucial ideas necessary for innovation came from outside the firm.

15. Myers, Sumner, and Donald G. Marquis. Successful industrial innovations; a study of factors underlying innovation in selected firms. Prepared for the National Science Foundation under contracts NSF–C321 and C556. [Washington, U.S. Government Printing Office, 1969]. 117 p. (NSF 69–17). HC79.T4M92.

Conducted by the National Planning Association, this study quantitatively examines what factors stimulate the application of scientific and technological knowledge in the railroad, computer, and housing industries. It concludes that demand pull is more important than technology push, that new information inputs frequently provide ideas for innovations, that personal contacts are the principal sources of information in innovation, and that management of innovation is a corporate-wide task too important to be left to a single specialized department.

16. Myers, Sumner, and Eldon E. Sweezy. Federal incentives for innovation; why innovations falter and fail; a study of 200 cases. Prepared for the National Science Foundation under contract NSF–C860. [Washington] 1976. 77 p. (Report R 75–04).

This study of 200 unsuccessful innovations in 81 firms found that once an innovation had been selected for development, it most often failed because of market and management obstacles. Other obstacles such as regulation, capital, and technology were less significant. The authors conclude that government options to stimulate innovation are limited and indirect at best. Beyond stimulating the economy, the government can do little about markets (procurement provides minimal leverage, they conclude), and even less about management patterns within private firms.

17. National Academy of Sciences. Applied science and technological progress; a report to the Committee on Science and Astronautics of the U.S. House of Representatives. [Washington, U.S. Government Printing Office] 1967. 443 p.

This volume contains 17 papers by Harvey Brooks, Robert Charpie, Edward Teller, and others, which attempt to assess the effectiveness of American applied research. The essays focus on the multidisciplinary mission-oriented laboratory and its relation to university laboratories, education for applied scientists, setting priorities for applied research, and on criteria for deciding whether a new technology is "ripe" for large-scale commercialization.

18. ———. Technology, trade, and the U.S. economy. Washington, 1978. 180 p. HC110.T4T43.

This report of a workshop attended by 39 participants from industry, labor, universities, Federal agencies, and private research organizations covers four areas: technology transfer and trade among OECD nations; relation of organized labor to technology transfer; technology transfer between OECD nations and the U.S.S.R.; and technology transfer to developing nations. The participants concluded that the U.S. lead in innovation has declined relative to OECD, but recommended that the Federal Government not restrain export of commercial technology.

19. National Academy of Sciences. National Research Council. Materials Advisory Board. Report of the Ad Hoc Committee on Principles of Research-Engineering Interaction. Washington, 1966. Various pagings. (Publication MAB-222-M.) [Available from the National Technical Information Service, AD 636 529.]

This study presents 10 case histories of successful industrial innovations with significant basic science-engineering interactions, each written by a Committee member who was personally involved in the innovation. The cases are highly diverse, and the findings highly qualified. Nonetheless, the study concludes that flexibility of support, frequent and close communication between organizationally independent groups, strong "champions" of ideas, and individuals working on well-defined missions were among the most critical factors in successful innovations.

20. National Commission on Technology, Automation, and Economic Progress. Technology and the American economy. [Washington, U.S. Government Printing Office] 1966. 115 p.

Established by order of Congress and composed of labor leaders, industrialists, social scientists, and economists, this Commission attempted to assess the effect of technological change on production, employment, social structures, and human values. They concluded that technological innovation does not play a determinative role in unemployment rates, but that it may affect whom among the labor force will be displaced.

21. Nelson, Richard R., Merton J. Peck, and Edward D. Kalachek. Technology, economic growth, and public policy. Washington, The Brookings Institution [1967]. 251 p. T21.N4.

This important study summarizes many previous views of the relationship between technological advance and the economy. The authors present an operational analysis of technological knowledge, and discuss how economic factors affect the inputs to the creation of the knowledge. They also examine how the economy adjusts to technical change. Finally, they present five public policy proposals to stimulate innovation (national institute of technology, large publicly-supported R. & D. programs, industry-specific public R. & D. programs, experimental procurement programs, and an industrial extension service).

22. Organization for Economic Cooperation and Development. The conditions for success in technological innovation. Paris, 1971. 169 p. T173.8.073.

This report presents 10 years of empirical research on factors which influence innovation, and discusses their implications for national policy. The report finds large differences in the deployment of R. & D. resources among OECD nations, and suggests national technological specialization and large cooperative efforts among OECD nations. The report concludes that to stimulate innovation risk taking must be rewarded, pressures must exist for change, and mobility and personal contacts must be encouraged within and among innovative institutions.

23. ———. Gaps in technology. General report. Paris, 1968. 41 p.

This study examines national differences among OECD nations in scientific and technical potential (i.e., "gaps") in five industries (scientific instruments, electronic components and computers, plastics, pharmaceuticals, nonferrous metals). Over 60 percent of the innovations originated in the United States. The United States also had the highest rate of diffusion of new technologies, but many other OECD nations had higher rates of increase of diffusion. The study recommends aggregating OECD national markets, and regional efforts to improve European innovative capability relative to the United States.

24. ———. Policies for the stimulation of industrial innovation. Analytical report, v. 1. [Paris, 1978]. 167 p. HC79.T4.074 1978.

This report summarizes a three-volume study of current policies for the stimulation of innovation (PSI) employed by 11 OECD nations. The study proposes a useful typology of PSI (based on instrumental structure, objectives, and costs), compares PSI in each nation, and concludes that OECD nations possess little objective data on the effectiveness of the PSI they employ.

25. Pavitt, K., and W. Walker. Government policies towards industrial innovation: a review. Research policy, v. 5, Jan. 1976: 11–97. Q180.A1R448.

These authors, from the Science Policy Research Unit of the University of Sussex, review what is known empirically about innovation performance and policies in Britain, France, the Netherlands, and West Germany. They discuss innovation in the industrial firm, compare the policy mechanisms employed in the four nations to stimulate innovation, and suggest avenues for further research aimed at evaluating the effectiveness of the various policy mechanisms.

26. Rogers, Everett M. Diffusion of innovations. New York, Free Press [1962]. 380 p. HM101.R57.

Rogers, a sociologist, wrote this study as a general textbook for students in the social sciences concerned with diffusion in the widest sense. He defines diffusion as the spread of a new idea through communication channels among actors in a social system. He reviews many studies of diffusion from various disciplines, and develops a theory of diffusion based on the theory of action of Parsons and Shils. Finally he lists 52 generalizations which summarize what is now known about the diffusion of innovation.

27. Schon, Donald A. Technology and change; the new Heraclitus. New York, York, Delacorte Press [1967]. 267 p. HD45.S355.

Schon critically analyzes technological change in American industry, and its impact on American society. Using case studies, he argues that invention has a large non-rational component; that innovation in firms occurs through confronting risk and uncertainty; and that major technological change frequently results from the invasion of one industry by another. Schon also offers suggestions for stimulating innovation, dealing with the structure of the innovative firm, Federal policies for innovation, and an ethic for the process of change.

28. Science Policy Research Unit. University of Sussex. Success and failure in industrial innovation; report on Project Sappho. London, Centre for the Study of Industrial Innovation [1972]. 36 p. HD45.B69.

This classic study compares 29 pairs of innovations, one successful, the other not, from the chemical and scientific instruments industries. It concludes that no single factor can account for the differences between successful and failed projects. Instead the study finds that successful innovators have better understanding of user needs, pay more attention to marketing, work more efficiently (not necessarily more quickly), make better use of outside technology and advice, and are older and have greater authority than their counterparts who fail.

29. U.S. Congress. Joint Economic Committee. U.S. economic growth from 1976 to 1986; prospects, problems, and patterns. Vol. 1. Productivity. Washington, U.S. Government Printing Office, 1976. 56 p. Vol. 9. Technological change. Washington, U.S. Government Printing Office, 1977. 61 p.
At head of title: 94th Congress, 2d session. Joint committee print. HC106.7.U59.
The four papers of these two volumes attempt to assess future economic trends regarding productivity and technological change. John Kendrick and Edward Renshaw discuss the many factors affecting productivity, argue over whether the rate of productivity growth will rise or fall over the next decade, yet agree that R. & D. investment is crucial for economic growth. Nathan Rosenberg argues that technological change occurs in numerous forms, and hence that government policy should stimulate high levels of economic activity rather than attempt to tinker with particular industries. Joseph Coates predicts continued high rates of technological innovation over the next thirty years, especially in consumer products.

30. U.S. Congress. Joint Economic Committee. Subcommittee on Priorities and Economy in Government. Priorities and efficiency in Federal research and development; a compendium of papers. Washington, U.S. Government Printing Office, 1976. 115 p.
At head of title: 94th Congress, 2d session. Joint committee print. Q180.U5.P66.
These five papers by Lester Thurow, Louis Fisher, Albert Rubenstein, William Carey, and Edwin Mansfield analyze how Federal R. & D. decisions are made, the priorities of different types of R. & D. activities, the results of publicly supported R. &. D., and their effects on the national economy. The papers include a variety of policy suggestions for reducing uncertainty and ignorance in the public policymaking process.

31. U.S. Department of Commerce. Commerce Technical Advisory Board. The role of new technical enterprises in the U.S. economy [by Richard S. Morse]. [Washington] 1976. 13 p.
Morse argues that young, high technology firms have contributed proportionally more to economic growth than have mature companies, and that since the late 1960's adverse changes in the business environment have restricted the development of new, small firms. He attributes these changes to reduced Federal R. & D. expenditures, tightened tax policies, regulation, reduction of liquidity, and a decline in venture capital supply, and recommends various changes in IRS and SEC rules to improve the climate for new, high technology firms.

32. U.S. Department of Commerce. Office of the Assistant Secretary for Science and Technology. U.S. technology policy; a draft study. n.p., 1977. 171 p.
This study contains many detailed policy recommendations to stimulate private R. & D. It proposes modification of regulatory inhibitions, improved venture start-up conditions, dissemination of innovation information to State/local governments, and promotion of exports of technology-intensive products. The study seeks a unified, holistic technology policy, but focuses mostly on options available to the Department of Commerce.

33. U.S. National Science Board. Science indicators, 1976. [Washington, U.S. Government Printing Office] 1977. 312 p. (NSF–77–1).
The *Science Indicators* series, of which this report is the third, attempts to describe quantitatively the condition of scientific research in the United States. This report presents massive amounts of data, mostly in tables, charts, and graphs, illustrating trends from the early 1960's through 1976. Some of the indicators include total resources for R. & D. Federal R. & D. expenditures, basic research in universities, inputs and outputs in industrial R. & D. and demographic characteristics of scientific and engineering personnel. No policy recommendations are included with the data.

34. U.S. National Science Foundation. Conference on technology transfer and innovation; proceedings. [Washington, U.S. Government Printing Office, 1967]. 126 p. (NSF 67–5), T174.3.C6 1966.
Planned jointly by the National Planning Association and NSF, this conference of 250 persons heard a variety of papers by Harvey Brooks, Gerhard Colm, Robert Charpie, and others. Among the more significant contributions were Brooks' distinction of two dimensions of technology transfer (vertical where scientic knowledge is converted to technology; horizontal where infor-

mation generated in one setting is borrowed by a firm in another setting), a systems analysis of the Bell Telephone Laboratories, and emphasis on the importance of technological as well as economic goals in the innovation process.

35. ———. The effects of international technology transfers on U.S. economy; papers and proceedings of a colloquium. [Washington, U.S. Government Printing Office] 1974. 114 p. (NSF 74–21). HC106.6.P28.

These four papers by Robert Stobaugh, Richard Caves, Gary Hufbauer, and Keith Pavitt analyze the relationship between technological innovation, foreign direct investment, licensing, transfer of American technology abroad, and domestic employment and economic welfare. They conclude that industries spending relatively high amounts for R. & D. also achieve high levels of exports, foreign direct investment, and licensing; that foreign nations obtain technological knowledge through United States' foreign investment and licensing; but that the United States also benefits from foreign investment and should not control international technology transfers.

36. ———. Preliminary papers for a colloquium on the relationships between R. & D. and economic growth/productivity. [Washington] 1977. Various pagings.

These five essays (by Eads, Kendrick, Mansfield, Nadiri, and Terleckyj) seek to summarize what has been learned since 1970 about the contribution of R. & D. to economic growth and productivity. They conclude that R. & D. contributions to growth differ according to industry and source of funding, that indiscriminate government intervention probably will fail to promote R. & D., and that problems of modeling and measurement are complex and require additional study by economists.

37. U.S. National Science Foundation. Research and development and economic growth/productivity; papers and proceedings of a colloquim. [Washington, U.S. Government Printing Office, 1972]. 84 p. (NSF 72–303).

These studies by Stewart, Mansfield, Fellner and Griliches conclude that R. & D. is an important contributor to productivity (though inadequate research tools make it difficult to assess the details of the relationship), that the United States is underinvesting in civilian R. & D. from an economic point of view, and that much more economics research is needed in these areas. The authors offer few policy recommendations.

38. ———. Science and technology: Annual report to the Congress. [Washington, U.S. Government Printing Office] 1978. 137 p.

This first annual science and technology report prepared by NSF for the Congress discusses some key developments in the funding and performance of American science and technology. It identifies an increase in Federal R. & D. funding (constant dollars) since 1975, a decline in national R. & D. expenditures relative to several other industrial nations, but no erosion of American superiority in R. & D. output. The report also finds a shift in industrial R. & D. away from long-term basic research to short-term development, and a shift in academic science to more applied research.

39. U.S. National Science Foundation. Office of National R. & D. Assessment. Serving social objectives via technological innovation: possible near-term Federal policy options. [Washington, U.S. Government Printing Office] 1973. 97 p.

These eight papers, written by NSF staff, seek to identify policy options for stimulating certain technological innovations which serve social objectives. They treat innovation in relation to government loan insurance, Federal regulatory practices, Federal procurement, special revenue sharing, promotion of energy conservation, small firms, training to facilitate diffusion of technology, and public technology.

40. U.S. National Science Foundation. Office of National R. & D. Assessment Technological innovation and Federal Government policy; research and analysis of the Office of National R. & D. Assessment. [Washington] 1976. 73 p. T173.8.U54 1976.

This report discusses the objectives of the Office of National R. & D. Assessment, the benefits of policy analysis of R. & D., and current economic theory of innovation. In an empirical section, the report finds among 17 industrial firms a median rate of return on innovation investment of 25 percent, that small firms conduct research more efficiently than large

firms, and that foreign direct investment makes only small contributions to international diffusion of technology.

41. U.S. Panel on Invention and Innovation. Technological innovation; its environment and management ["Charpie Report"]. Washington, U.S. Government Printing Office, 1967. 90 p. HC110.T4.A55.

This classic study helped define many crucial concepts in the analysis of innovation, such as the distinction between R. & D. and innovation and the greater innovative efficiency of small firms. The Panel identified taxation, finance, and competition as the critical factors affecting invention and innovation. While it recommended no major changes in current laws in these areas, it did propose many specific adjustments to improve the environment for innovation and to increase basic understanding of the innovative process.

42. Universities-National Bureau Committee for Economic Research. The rate and direction of inventive activity; economic and social factors. A conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth for the Social Science Research Council. Princeton, Princeton University Press, 1962. 646 p. HD69. I75U5.

The 23 papers collected in this volume were presented at a conference held in 1960. Written mostly by economists, these papers cover a wide range of topics, including problems of definition and measurement of inventive activity, macro-quantitative analysis, nonmarket factors such as organization within the firm and motives for individual inventors, efficiency in R. & D. welfare economics and invention and several case studies. Most of the essays are purely descriptive and include few policy suggestions.

THE PROCESS OF TECHNOLOGICAL INNOVATION IN INDUSTRY: A STATE-OF-KNOWLEDGE REVIEW FOR CONGRESS

By Mary Ellen Mogee*

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*Analyst in science and technology, Science Policy Research Division, Congressional Research Service, Library of Congress.

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Abstract

This paper summarizes the current state of knowledge with respect to the process of technological innovation in industry. Technological innovation is defined as the process by which society generates and uses new products and manufacturing processes. It includes the activities ranging from the generation of an idea to its widespread use by society. The activities include the generation, research, development, introduction, and diffusion of new and improved products, processes, and services for public and private use. Although civilian-oriented industrial innovation is largely a private sector activity, Government has an interest in its socioeconomic impacts on the Nation as a whole.

Industrial innovation may be regarded as an investment activity, and like other investments, it responds to economic forces, such as demand and costs. It is also affected by technical and institutional factors, which guide the direction of innovation and determine how rapidly innovation can respond to economic signals.

The process of innovation may be viewed as a process of uncertainty reduction. As the idea proceeds through the stages of innovation, the investment increases and information is produced that allows a firm to more accurately estimate a project's economic and technical potential. As the investment becomes larger, the evidence must increasingly point to the probability of profitable production to justify continuation. The various types of uncertainty involved in innovation are described, as well as their effects on innovation decisionmaking and the types of innovations that are undertaken.

Relationships between technological innovation and such aspects of industrial organization as firm size, industrial concentration, market entry, diversification, and spinoff firms have important implications for public policy. Research findings, however, have been largely contradictory and inconclusive. Recently developed theories of industrial life cycles may help explain some of these findings.

The diffusion of innovations among industry, which is the means by which innovation's economic and social impacts are made, may take a long time. Factors affecting the rate of diffusion of innovations are similar to those affecting the generation of innovations: for example, the cost of the innovation and the advantage it offers. As an innovation diffuses through industry, it may change as it is improved and modified.

The time lags involved in the innovation process are often lengthy. It is not necessarily wise, however, to shorten the innovation process too much, since the lag may be caused by the absence of a market for the innovation, bottlenecks in related technologies, or negative societal impacts.

The paper's findings have implications for congressional decisionmaking for innovation policy. Listed here in brief form, they are discussed in more detail in the paper:

Innovation is a complex process and our understanding of it is limited;

The essence of innovation is uncertainty about the outcome;

The importance of market factors to industrial innovation is difficult to overemphasize;

Innovation is a costly and time-consuming process;

The economic and social impacts of innovation are made through their diffusion;

Basic scientific research seems to underlie technological change in complex and indirect, but important, ways;

The innovation process differs from industry to industry, sector to sector, and even firm to firm;

Financial and manpower resources are necessary, but not sufficient, for innovation; and

Both large and small firms play important roles in innovation and those roles differ from industry to industry.

INTRODUCTION

This paper is one of a series prepared for the Special Study on Economic Change of the Joint Economic Committee. The basic premise of the Special Study on Economic Change is that economic, social, political, international, and technical conditions have changed, and are still changing markedly. This suggests that conventional wisdom and established economic tools may not be sufficient for making sound economic policies. The area of industrial research and development (R&D) and innovation is 1 of 10 major areas the SSEC is investigating.

Although little is known about how they impact the economy, industrial R&D and innovation historically have been important contributors to economic growth. Not only have such innovations as the telephone, the automobile, and the electronic computer contributed to growing economic output, they have qualitatively changed the life style of the American people. After World War II, there seemed to be an explosion of innovations from American industry such as computers, the transistor and integrated circuit, containerized shipping, microwave ovens, Polaroid "instant" cameras, and Xerox copiers. Throughout much of the 1960's expenditures for R&D rose rapidly in both industry and the Federal Government. By the early 1970's, however, concern had begun to grow among the public and in government about our seeming inability as a nation to apply technology to the solution of some of the pressing problems in the civilian sector, such as environmental pollution, energy, housing, urban transportation, and public services. There was also concern that the United States was beginning to lose the technological superiority which it had maintained over other nations in the aftermath of World War II. These concerns have grown in recent years, as reflected in articles with such titles as "The Silent Crisis in R&D," "The Breakdown of U.S. Innovation," and "Vanishing Innovation."

In May 1978, President Carter indicated the importance attached to these problems by his Administration's undertaking a domestic policy review on industrial innovation. On the other hand, the National Science Foundation said in the First Annual Science and Technology Report to the Congress (1978), that: "Neither the available economic nor technical indicators provide hard evidence of an eroding U.S. technical position which can be tied to negative economic consequences." (p. 41)

In the context of this concern and the lack of agreement on the nature of the problems, this paper summarizes the state of knowledge with respect to the process of technological innovation in industry. This paper does not assess the innovation problem, rather it attempts to provide an improved understanding of the innovation process and the factors that influence its rate and direction as background for the consideration of current problems and their implications for Congress. The thesis is that, although knowledge remains limited, recent research has resulted in more information about industrial innovation than most policymakers realize. The task is to summarize and translate these research findings for Congress. To enhance the paper's readability, references have been kept to a minimum and are provided in parentheses in the text. A list of references is at the end of the paper.

Summary and Implications for Congress

A better understanding of the innovation process as it occurs in private industry is necessary to make informed decisions on whether to stimulate or direct industrial R&D and innovation and to understand in what situations increased innovation is likely to be an appropriate and effective solution to perceived problems and what kinds of approaches are likely to be successful in stimulating innovation. This section summarizes the major findings of the state-of-knowledge review of the process of technological innovation in industry and their implications for Congress. The findings are keyed to the relevant chapters of the paper, where supporting detail and documentation may be found.

A. Innovation Is a Complex Process and Our Understanding of It Is Limited

Technological innovation is the process by which society generates and uses new products and manufacturing processes. It includes the activities ranging from the generation of an idea to its widespread use, including the generation, research, development, commercialization, and diffusion of new and improved products, processes, and services for public and private use. (Chapter I)

There are numerous models of the innovation process, many of which show a linear progression of innovative activity through stages from idea generation through commercialization and diffusion. These models are highly oversimplified because, in real life, the progress of an innovation is rarely that straightforward. Sometimes stages are shortened, skipped, or overlapped. Sometimes a retreat must be made to more fundamental work. Throughout the process there is communication and feedback among groups involved in the various activities. The activities commonly occur in different organizations, at different times, and even in different countries. There are frequently multiple paths of activity leading to an innovation. (Chapter I)

Innovation is a dynamic system composed of various organizations that perform R&D, manufacture and distribute products, use the innovations, and finance innovation activities. Not only must the innovating firm be considered, but so must its suppliers and customers, sources of finance, sources of scientific and technical knowledge, and other institutions. The elements of the innovation system are interdependent;

for the innovation process to proceed smoothly, all the components of the system must act in harmony (Chapter VI)

Innovation is affected by external factors—such as economic, social, and political factors—in ways that are not well understood. Economic factors affect the profit incentive which drives innovation. Such factors include the growth of demand, the structure of industry, and the adequacy of available financing. Social factors such as the value attached to creativity and innovation, and the attitude toward risk have important effects on innovation. Political factors are also important; besides their role in maintaining a stable and growing economy, government policies have other important effects on innovation, both intended and unintended. (Chapter II)

There are many difficulties facing theory and research on technological innovation. Innovation processes vary across industries and over time, due to differences in structural conditions, incentives, and other important variables. The inherent difficulties in defining and measuring intangible concepts such as innovation result in inconsistent research findings, restricting the comparability of studies and the cumulation of knowledge. (Chapter I)

The complexity of the innovation process and the limitations of our knowledge with respect to it make innovation a difficult issue with which to deal and mitigates against "quick fixes." Policy decisions should be made with the best information and analysis available. Policy should be flexible and made on a "learn-as-we-go" basis. Initial policy actions or programs could be small-scale experiments with parallel approaches, planned to provide information on the desirability of continuing the programs.

B. The Essence of Innovation Is Uncertainty About the Outcome (Chapter III)

Since innovation involves the creation and use of things that are fundamentally *new*, there is often little experience on which to rely and real difficulty in predicting whether a given project will be technically and commercially successful. Thus it is not surprising that innovation is a process of elimination; most innovation projects fail. Large sums of money can be lost and firms may even be forced out of business by failed innovation projects. On the other hand, successful innovations sometimes have great rewards for the innovating firms and for society at large.

Risk and uncertainty are terms used to refer to the high chance of failure that exists in innovation. They represent different degrees of a chance of failure. Risk is the probability of failure and as such can be calculated by statistical methods. Uncertainty, on the other hand, describes situations where the probability of success or failure cannot be calculated. Uncertainty dominates the innovation process.

In general, uncertainty is caused by imperfect information and the inability to predict what will happen in the future. The degree of uncertainty tends to increase with the length of time it takes to develop an innovation and with the degree of technological advance that is sought. Although risk and uncertainty are especially high in the early stages, they are associated with all phases of innovation activity and frequently remain at substantial levels even when the new product or process is introduced to commercial use.

There are different types of uncertainty. Some uncertainty is due to lack of knowledge of what the competition is doing. General business uncertainty refers to lack of knowledge about future economic conditions and business environment. Technical uncertainty concerns standards of performance achievable under various operating conditions and within certain cost limits. Market uncertainty involves the magnitude of demand for the new product as reflected in sales growth, and the innovation's effect on the innovating firm's competitive position. Another source of uncertainty in innovation is government policy. Recently industrial leaders have been complaining that one of the most difficult aspects of governmental regulation with which they must deal is the uncertainty about what new regulations may be promulgated in the future, what the standards will be, and how thoroughly they will be enforced.

The process of innovation may be regarded as a process of uncertainty reduction. Uncertainty tends to be highest at the basic research end of the spectrum. Each succeeding stage of innovation activity, such as research and development, produces information that allows the firm to estimate more accurately the project's technical and economic potential. As the required investment becomes larger, it is undertaken only if the evidence increasingly points to the probability of profitable production. Because of uncertainty much of industry's innovative activity is focused on relatively small advances of a short-term, low-risk nature. A high level of uncertainty tends to be accepted only when the firm is forced to accept it (e.g., by competitive pressure), can afford to accept it (e.g., has a large portfolio of innovation projects such that the failure of one will not threaten the firm's existence), or does so unwittingly (e.g., does not accurately estimate the probable return on investment).

The stakes that are involved in major innovation, whether undertaken with private or public funding, should be recognized. To oversimplify, minor technical advances tend to be relatively easy to accomplish, require small investment, but individually result in small benefits. Major technical changes tend to be difficult to accomplish, require significant investment, but may result in significant benefits. Of course, exceptions to these generalizations may occur.

It may be desirable to learn the conditions under which firms will undertake uncertain innovation projects in the national interest. Another approach could be policies that reduce the uncertainty facing the firm through: (1) The generation of additional technical or market information; (2) sharing the possible losses or enhancing the possible rewards, or (3) increasing the predictability of governmental policy changes affecting firms' innovative behavior.

Since it is to a large extent a process of uncertainty reduction, the innovation process serves a useful function if it reveals, before the expenditure of large sums of money, that a concept is technically unfeasible or economically unattractive. Since failure of any single project is to be expected, Federal policy might emphasize parallel approaches and a "portfolio" perspective, at least in the earlier, relatively inexpensive stages of innovation. This would help assure a better decision when the time comes to invest in one or two expensive demonstration projects.

C. The Importance of Market Factors to Industrial Innovation Is Difficult to Overemphasize

An important, if not the most important, incentive for an industrial firm to undertake innovation is expected profit. Most research indicates that sustained R. & D. programs or innovation are associated with growth and profitability. The direct average gross rate of return on private R. & D. expenditures appears to be 30 to 40 percent. Government's chief concern, of course, is with the societal impact of innovation. Economic studies have found that the return of private R. & D. expenditures to society may be even larger than those to the firm, perhaps by a factor of two. But in many cases the expected benefit to the firm is not large enough to justify its investment, although the benefits to society may be substantial. Under those conditions it may be desirable for Government to intervene to facilitate the innovation's being brought into use. (Chapter II)

Innovation normally responds to market forces and tends to be directed toward those areas where demand is growing or cost savings are possible. Expansion or contraction of a market may stimulate or retard, respectively, innovation in that area. Research and development and innovation are frequently regarded as optional expenditures and may be among the first to be cut when budgets are reduced. When the economy slows down, growth in demand slows, so innovation may also slow. This may be one explanation for the slowing of innovation perceived in this country in the last decade. (Chapter II)

Innovation decisions are investment decisions that trade off expected costs and revenues. As such, they compete among each other and with other possible investments for the firm's resources. Those investments are chosen that offer the highest return. Due to the uncertain nature of innovation it is difficult to predict the returns. Thus, some projects may be undertaken that prove to be unprofitable. The higher discount rate applied to innovation projects may discourage investment in them relative to non-innovative projects. Moreover, increased uncertainty in the economic, social, and political spheres may result in a slower rate of innovation. (Chapter III)

Public policy for innovation should recognize the importance of market factors in determining the selection of innovation projects and their success. Although new technology may be intellectually exciting, unless it offers some commercial potential there will be little incentive for industry to introduce it to the market. Federal policy for innovation should, wherever possible, reinforce and help to perfect market forces rather than substitute for them. Government policy to stimulate innovation may act by creating, expanding, stabilizing, aggregating, or guaranteeing markets for innovative products. Government policies that operate in the opposite direction may retard innovation.

Although it is commonly claimed that market demand "pulls" innovation more effectively than technology "pushes" it, this represents an oversimplification. A market demand cannot be met if the technology does not exist or cannot be created to satisfy it; both the market demand and the technological opportunity are necessary. The key to successful innovation is the ability to match the demand with the technology, yet this is one of the most difficult problems. For any given innovation, both technical and commercial conditions must be right. The innovation must meet technical performance standards within a cost range determined by the market and sufficient demand for the innovation must exist to ensure a minimum level of profitability. (Chapters II, III)

One of the key problems with Federal programs to commercialize new technologies, as in the energy area, has been the failure to consider the market for such technologies once developed, or to involve potential users of the innovation early in the process. Moreover, it should be recognized that market prediction is difficult even for industrial firms, let alone for the Federal Government, which has relatively little knowledge of commercial markets or ability to analyze market potential. Some people suggest that the later stages of innovative activity, which are heavily dependent on commercial know-how, are best performed by private industry with minimum Federal involvement.

Technological innovation is a key element of competition in many industries. Technological innovation may also be the basis for entry of firms into an industry or for the creation of whole new industries. The classic case is the automobile industry, which put the horse carriage industry out of business. It is likely that the relationship between market structure and technological innovation varies over the life cycle of an industry or technology, in such a way that major innovations are more likely and easier to accommodate early in the life cycle; later, major innovations tend to come from outside the industry and may be disruptive. (Chapter IV)

The relationship of the level of competition in an industry, which is frequently measured in terms of concentration, to innovation is not clear. There is some evidence that an intermediate level of competition may be most conducive to innovation. On the other hand, successful innovation often leads to increased market share for the innovating firm. Thus, antitrust concerns may prevent some innovations from being commercialized. (Chapter IV)

D. Innovation Is a Costly and Time-Consuming Process

Innovation is a costly and time-consuming process. Ideally an innovation decisionmaker would like to know how much an innovation project will cost and how much time it will take to complete. These predictions are extremely difficult to make, however, and contribute to the uncertainty of innovation. (Chapter III)

It is often necessary to invest large sums of money and to work for long periods to accomplish major innovations. The cost and time required increase with the degree of technical advance sought. To some extent, cost and time can be traded off against each other. Thus, one advantage of Federal Government support is its large resources, which enables it to spend more money to speed up the completion of projects. (Chapters II, VII)

The cost of innovation is not limited to R&D costs. R&D may account for 10 to 60 percent of innovation costs, depending in part on the industry. Often, costs escalate dramatically in the later stages of innovation and a large proportion of innovation cost may be required for pilot plant work. Resources devoted to building the scientific base of an industry may pay off by reducing the cost of later innovation work. (Chapter II)

Sometimes the high costs of commercialization are used to rationalize Government involvement, but such involvement in this essentially commercial activity has had mixed results. (Chapter II) Government-supported projects tend to become difficult to cut off, as investment of funds and prestige increase. Frequently, large-scale public commitments are made before technical and market uncertainties have been sufficiently reduced. Thus, although a strong case may be made for governmental support of basic research and some exploratory technological development, commercial firms may be better equipped to make the hard-nosed decisions involved in commercializing new technology—including cutting off expenditures when the prospects seem dim.

There is frequently an interest in speeding up the process of innovation. Often the reason for delay may be the failure of a related technology to be developed sufficiently or the lack of a large enough market. Conceivably Congress could attempt to alter these situations by increasing funding for development of related technologies or by guaranteeing Federal markets for innovations. It should be recognized, however, that speeding up the process generally increases the cost and may have adverse effects on technical quality. Moreover, innovation may be *too* fast if applications become widespread before the limitations and risks are fully known, or if considerable social and economic adjustment is involved. (Chapters VII)

It is sometimes suggested that innovation is "speeding up" naturally—that is, the innovations take less time for development now than in the past. The evidence on this issue, however, is inconclusive. It is possible that different factors work in different ways. Modern marketing may have reduced waiting periods, but the inventions and innovations undertaken today may be more difficult and take longer. (Chapter VII)

E. The Economic and Social Impacts of Innovation Are Made Through Their Diffusion (Chapter V)

Diffusion is the spread of an innovation. It is an important part of the innovative process because it is only through the spread of innovations that their economic and social impacts are made. To modernize U.S. industrial technology, and thereby improve productivity and international competitiveness, it is necessary not only to assure the introduction of innovations but also their widespread use in industry. Moreover, the spread of an innovation affects not only the industry using that innovation but also its customer firms. The spread of innovations may occur through three mechanisms: the growth of the original innovator; the adoption of the innovation for the same purpose by other firms; and the application of the innovation for other purposes. Diffusion may take a long time. Sometimes it may take decades for an innovation to be adopted widely, while in other cases diffusion occurs quickly.

The diffusion of an innovation occurs as industrial firms adopt it for use in their operations. The adoption decision is an investment decision in which the firm determines whether the innovation will contribute as much to firm objectives as alternative investments. Since adoption often entails purchasing or building new plant and equipment, it may involve considerable risk or uncertainty. Even if a technology has been in use elsewhere, for each new user it is an innovation in terms of the risk and uncertainty it poses to the firm. The decision to adopt will also be affected by the availability of financial capital and other factors affecting investment generally, as well as competitive pressures from other firms.

The rate of diffusion of an innovation appears to be determined in large part by four factors: the relative advantage of the innovation over older methods or products; the extent of the uncertainty associated with using the innovation; the rate at which the initial uncertainty can be reduced; and the investment required to try out the innovation. The speed with which a firm adopts an innovation appears to be related to the perceived profitability of its use of the innovation. Large firms may be quicker to adopt costly innovations than small firms. Some innovations are too costly for small firms to adopt at all. Hence, a trend toward costly new equipment may eliminate small firms.

A comprehensive innovation policy would be concerned with the widespread diffusion of innovations, as well as the initial introduction of innovations. One successful Federal program to stimulate the widespread use of new technology is the Agricultural Extension Service, which combines an R&D capability with an extension service. One key to its success appears to be the close coupling of user needs with the R&D function.

Like incentives for innovation, incentives for industrial adoption may be based on increasing the profitability of use of the innovation, decreasing the risk or uncertainty associated with its use, or reducing the costs. Programs to stimulate adoption of new technology will, however, probably have to deal with firms that are traditional and noninnovative, which may pose additional problems.

F. Basic Scientific Research Seems To Underlie Technological Change in Complex and Indirect, but Important, Ways (Chapter II)

Although it is difficult to establish a simple relationship between a particular scientific advance and a particular technological advance, gains in scientific knowledge increasingly affect the rate and direction of technological change. This is particularly true for major innovations. Technology does not always follow science; in fact, sometimes the reverse is true. For example, the science of thermodynamics developed after the invention of the steam engine.

Basic research, which is performed largely in universities, contributes to industrial innovation by enlarging the pool of scientific knowledge which may be used by industry in the development of new products and production processes. Science seems to act as an "engine" of technology, without which specific innovations might be delayed or prevented and technological progress might eventually stagnate. Basic research seems to reduce the cost of later stages of R&D and innovation by providing improved knowledge of the likely fruitful and unfruitful paths for development.

The utilization of basic research in innovation is usually indirect and delayed, often by 20 to 30 years. The main modes of transfer of basic research results are through reports and journals and the primary and continuing education of industrial scientists and engineers. Sometimes the results of basic research are transferred quickly into applications; this usually occurs when there is an urgent technological problem which requires improved scientific understanding. Research may also be quickly transferred in the science-based industries, such as chemicals and electronics. The utilization of basic research in industrial innovation depends not only on the supply of basic research results but also on the demand for them in industry.

While industry tends to invest in R&D projects with near-term commercial potential, Federal funding of basic research in universities seeks to ensure that the supply of scientific knowledge is renewed so that innovation and productivity improvements will be possible in the long-term future. Thus, current Federal support of basic research in universities complements industrial R&D funding by providing funds where there is little incentive for industry to invest, and takes advantage of the natural capabilities of universities. Congress may wish to re-examine Federal relations with universities in the light of the important national role of universities and their current financial problems, It may also be desirable for the Federal Government to develop further the scientific bases relevant to the technologies of certain industries, since, in the absence of economic or institutional barriers, an improved scientific base may make it easier to innovate in those industries.

G. The Innovation Process Differs From Industry to Industry (Chapter II)

The incentive to innovate and the ease of innovating vary significantly across industries. In some industries, due to the balance of incentives and costs, the industry's suppliers or users may be the primary source of innovations.

Industry may have a number of objectives: profit is one; others may include simple survival, meeting governmental regulatory standards, meeting foreign competition, entering new markets, keeping old ones, and reducing reliance on increasingly expensive materials. Innovation competes with other means of meeting firm objectives and thus the expected benefits from innovation are compared with those of alternative actions. The level of innovative activity in an industry depends on the expected profitability of innovation in that industry. If investment in innovation is not expected to be as profitable as other investments, firms may turn to investments in diversification and integration instead. There are many problems facing an industry and innovation may not be the most effective solution to those problems. Moreover, since management's *perception* of expected profitability guides investments, the attitudes of top industrial managers toward technological change and long-term investment are also important.

The costs of innovation vary from industry to industry, depending on the nature of the products produced and the capital-intensity and flexibility of production processes. Perhaps more important, costs of innovation relative to the assets of firms vary across industries. Thus, in some industries only the largest firms can afford new product development. Further, the costs of different stages of the innovation process vary across industries, making certain stages more critical in some industries than in others. For example, R&D accounts for a relatively large part of total innovation costs in some industries (e.g., electrical machinery) and for a relatively small part in others (e.g., chemicals). In some industries, the costs of pilot plant and manufacturing start-up are almost prohibitive relative to firm resources. The profitability, rate of growth, and availability of investment capital to industries also affect their ability to finance innovation.

The underlying science and technology base is related to the ease of innovating in various industries. Innovation seems to be easier in industries with better-developed science bases and with technologies to which current "technological trajectories" are readily applicable.

Industries also vary in the nature of their policy environments. Some industries are heavily regulated, such that innovation is channeled in certain directions. Large firms in other industries face a constant antitrust threat so that innovations that may increase market share are avoided.

In view of the variation in the conditions of innovation across industries, it may be wise to consider industry-specific innovation policies or to allow sufficient flexibility to tailor programs to the needs of particular industries. Analysis of policy proposals must examine innovation at the level of industries, firms, and even product lines. For example, it is necessary to identify the sources of innovation in an industry to properly target incentives.

H. Financial and Manpower Resources Are Necessary, but Not Sufficient, for Innovation (Chapter II)

The firm must have access to the requisite financial and manpower resources for innovation to proceed. The rate of technical progress in an industry depends, among other things, on the amount invested in improvement of the industry's techology. The availability of resources is not sufficient to stimulate innovation, however, for innovation must compete with other resource needs. If other investments appear more attractive, resources will be diverted to them. High rates of interest and inflation tend to make short-term incremental projects more attractive than long-term innovative projects. Thus, although Congress may desire to augment the funds available for innovative activities in certain industrial sectors—through Federal R. & D. spending, procurement, loans, or subsidies—such funds may be invested in noninnovative activities if the economic incentives are not right. The subtleties of distinguishing innovative and noninnovative activities may make it difficult for Congress to formulate policy to stimulate innovation. Indeed, Federal economic policies may be acting to constrain the resources invested in innovation. The interactions between economic policy and technology may make it desirable to integrate more closely economic and technology policymaking.

I. Both Large and Small Firms Play Important Roles in Innovation and Those Roles Differ From Industry to Industry (Chapter IV)

Research, development, and innovation are carried out in firms of all sizes, although R. & D. expenditures are concentrated in large firms and most small firms perform no formal, organized R. & D. at all. The relative importance of large and small firms appears to vary by industry. The largest firms do a disproportionate amount of innovating in those industries in which innovation is very costly relative to the size of the firms. Small firms make significant contributions in industries which are not especially capital-intensive, where innovation is not very expensive, and in the less expensive early stages of innovation. Small firms and independent inventors have been the sources of some of the most important inventions of this century, but these inventions have often required the resources of large corporations to commercialize them. Increasing complexity of technology and cost of development make it more difficult for small firms to innovate and compete.

There is a tendency in most industries for larger firms to be more R&D-intensive than smaller firms. This is largely due to the majority of small firms which perform no R&D at all, and the concentration of federally funded R&D in large firms. Evidence suggests that small firms that perform R&D and innovation do so more efficiently than large firms.

The entry of new firms into a market appears to be an important stimulus to competition and innovation, but barriers to entry frequently exist in terms of capital requirements, regulatory exclusions, or minimum R&D level requirements. It appears that innovation thrives best in industries with intermediate entry barriers.

New firms based on new technology are often spinoffs from a larger firm or a university. The spinoff phenomenon is important in the diffusion of technical know-how and the development of industries, witness the U.S. semiconductor industry. The formation of new, high-technology firms seems, however, to have decreased in the 1970's, presumably due to the increasing difficulty of obtaining financing and meeting regulatory requirements. The financing problems may have been somewhat alleviated by the Tax Reform Act of 1978.

Small firms can make significant contributions to industrial innovation. Thus the problems of establishing and financing small high-technology firms today may concern public policymakers. On the other hand, limitations of small firms and the conditions under which they can make a contribution should be recognized. Moreover, it should be noted that the majority of small firms perform no R&D or innovation and it is difficult to distinguish between these and high-technology firms in aggregate data on small business.

With regard to large firms, the evidence indicates that they have been playing an increasingly preponderant role in both invention and innovation. In most industries, however, the largest firms are no more innovative relative to their size than moderate-size firms. This does not seem to support arguments that breaking up large corporations will adversely affect innovation in those industries. Nonetheless, some innovations are so expensive that only firms with relatively large resources can undertake them. Consequently, some consolidation may be desirable in fragmented industries.

J. Conclusion and Recommendations for Future Research

One of the main conclusions arising from this paper is that the process of technological innovation in industry is complex and full of uncertainties, and understanding of it is limited. Nonetheless, a body of research findings has accumulated over the past 20 years that contains more knowledge about the innovation process than is widely appreciated. This paper has analyzed that research to summarize for Congress what is known about industrial innovation to contribute to discussion and debate on what will surely continue to remain an important issue on the national scene.

In the course of preparing this paper, it became obvious that certain important issues would need to be addressed in future efforts. First, more integration of the findings reviewed in this paper is necessary. For example, it is possible that integration of findings on industrial organization and uncertainty could yield more information for public policymaking. Second, more empirical research needs to be done on the effects of government policies on industrial innovation. Specific policy proposals need to be analyzed carefully in the light of what is known about innovation processes. This information is critical if Congress desires to change policy to stimulate or direct innovation. A body of relevant material has been accumulated by the Domestic Policy Review on Industrial Innovation and other activities, but this needs to be augmented. Third, there is a need for a careful delineation of what the "innovation problem" is. The problem has been insufficiently defined in policy debates. This must be done to evaluate the appropriateness of recommendations made for policy changes to stimulate innovation. Fourth, this paper has highlighted the difficulty of generalizing about innovation. It seems clear that, to be helpful to policymakers, innovation analysis must proceed at the level of industries, firms, and even product lines.

I. Definitions, Limitations, and Rationale

A. Definitions

Technological innovation is the process by which society generates and uses new products and manufacturing processes. It includes the activities ranging from the generation of an idea to its widespread use by society. The activities include the generation, research, development, introduction, and diffusion of new and improved products, processes, and services for public and private use. This paper focuses on innovation as it occurs in the private industrial sector.

Technology, as used in this paper, is the body of knowledge pertaining to the industrial arts. This definition is narrower than some others.

(See U.S. Library of Congress, pp. 99–100.)[1] According to Mansfield, "[Technology] consists of knowledge used by industry regarding the principles of physical and social phenomena (such as the properties of fluids and the laws of motion), knowledge regarding the application of these principles to production (such as the application of genetic theory to the breeding of new plants), and knowledge regarding the day-to-day operations of production (such as rules of thumb of the craftsman)." (1968A, p. 10) Technological change is the advance of this body of knowledge, often taking the form of new methods of producing existing products, new designs which enable the production of products with important new characteristics, and new techniques of organization, marketing, and management. (Ibid., p. 11) Technology is also used to mean the physical embodiment of knowledge in production equipment and new products. (Freeman, p. 18) Some technological change consists of better methods and organization that improve the efficiency of both old and new equipment; this is so-called disembodied technological change. Many changes in technology, however, must be embodied in new equipment to be used; this is capital-embodied technological change. (Mansfield, 1968A, pp. 30–31)

Technological change should be distinguished from scientific advance. Science is directed toward understanding, whereas technology is directed toward use. The distinction between science and technology is imprecise, but important. Although technological change sometimes relies on new scientific principles, this is not always the case, and sometimes scientific advances follow a technological change. For instance, the science of thermodynamics followed the invention of the steam engine.

One phase of the innovation process that has been identified is invention. An invention has been defined as "a prescription for a new, potentially useful product or process that was not obvious to one skilled in the relevant art at the time the idea was generated" (Mansfield, 1968A, p. 50) An invention when applied commercially for the first time is called by economists an innovation. Invention and innovation are distinguished on the grounds that an invention has little economic significance until it is applied commercially. All inventions do not lead to innovations, in fact the majority do not. The road from invention to commercial introduction and subsequent diffusion is often long and hazardous.

Research and development are important parts of the innovation process. In the United States, data on the conduct of research and development are collected by the National Science Foundation. The definitions used by the Foundation are:

(*a*) *Research* is systematic, intensive study directed toward fuller scientific knowledge or understanding of the subject studied. Research is classified as either basic or applied.

In *basic research* the investigator is concerned primarily with gaining a fuller knowledge or understanding of the subject under study.

In *applied research* the investigator is primarily interested in a practical use of the knowledge or understanding for the purpose of meeting a recognized need.

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[1] References are at the end of the paper.

(*b*) *Development* is systematic use of the knowledge and understanding gained from research, directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes. It excludes quality control, routine product testing, and production. (NSF, 1977 A, p. 48)

Although they are commonly conceived as occurring before commercialization, R&D are also involved in the diffusion and adoption of new technology.

Diffusion is the process by which innovations spread. Once a new product has been introduced and proven successfully by one firm, other firms may copy it (legally or illegally), produce a similar product, and market it. Once a new production process or piece of equipment has been used successfully by one firm, other firms may adopt that same process or piece of equipment. In this way, what was once an idea in the mind of one person is brought into existence and may become widespread throughout the economy. Diffusion is an important part of the innovation process because it is through the spread of the innovation that its impacts on the economy and society are felt. In this context, so far as human behavior is concerned, it is not as important whether technology is objectively new as whether it is perceived as new in the user's experience.

The output of the process of technological innovation is a flow of innovations. There are various types of innovations. A distinction is commonly made between product innovations and process innovations. Product innovations are new or improved products. Process innovations are changes in the production process itself. This distinction is somewhat arbitrary, since what is a product innovation to one firm may be a process innovation to the firms it supplies. A numerically controlled machine tool, for instance, is a product innovation for firms that previously produced manually controlled machine tools, but it represents a process innovation for firms that use machine tools in the production of airplane components. More important, the distinction is arbitrary because new processes and products are frequently intertwined in the same innovation.

Another distinction is often made betwen major (or radical) and minor (or incremental) innovations. These terms, however, may be used in a variety of ways. The most common meaning seems to denote a difference in the level of technological advance sought or achieved. In this sense, a major innovation represents a relatively large change from pre-existing technology, while a minor innovation represents a relatively small change. Another meaning is also often encountered. This refers to the economic impacts of the innovation, either to the firm in terms of profits or to society in terms of economic growth. (It should be noted that innovations can also have negative economic consequences, in terms of losses to the firm and society). In this sense, a major innovation may be one that is very profitable for the firm, while a minor innovation is one that is less profitable. Finally, major and minor may refer to the social impacts of an innovation. For instance, the automobile was a major innovation in the sense that it has caused major changes in the American life-style, while the ballpoint pen although important, has caused less obvious change in society.

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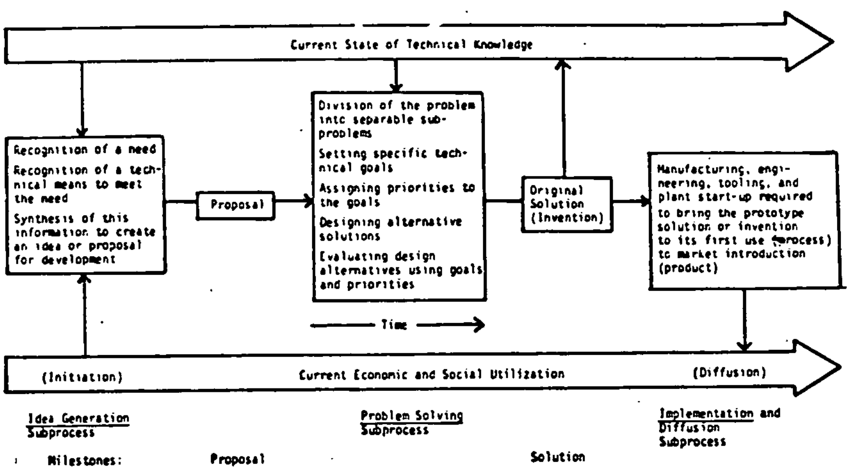
There are many conceptual representations of the process of technological innovation. Although commonly called models, most of these are not mathematical models that allow prediction of outcomes. A recent analysis concluded that no models of the innovation process exist that are satisfactory for policy analysis but preliminary work is beginning to develop such models. (Baker and Sweeney) The basic problem with modeling the innovation process is its complexity. Many models show a linear progression of innovation activity through stages from idea generation to commercialization and diffusion, occurring within an environment of technical, economic, and social factors. Figure 1 shows just one of the many models that have been proposed. These models are highly simplified; in real life the progress of an innovation is rarely that straightforward. Sometimes stages are shortened, skipped, or overlapped. Sometimes a retreat must be made to more fundamental work. Throughout the process there is communication and feedback between groups involved in the various activities. The activities commonly occur in different organizations, at different times, and even in different countries. There are frequently multiple paths of activity leading to an innovation. Despite their shortcomings, the models serve to remind managers and policymakers of the phases of development that an innovation must go through to succeed on the market. Moreover, they serve as guides to important problem areas for analysis.

FIGURE 1.—The Process of Technological Innovation: An Example of a Model



Source: James M. Utterback, "The Process of Innovation: A Study of the Origination and Development of Ideas for New Scientific Instruments," IEEE Transactions on Engineering Management, Vol. EM-18, No. 4, Nov. 1971, pp. 124-131.

Innovation may be viewed and analyzed in many ways:

As an investment process;
As a problem-solving process;
As a learning process;
As an uncertainty-reducing process; and
As a creative process.

The investment perspective emphasizes cost, returns, and profitability. The problem-solving perspective emphasizes the matching of market need with technological opportunity. The uncertainty-reduction perspective emphasizes the effects of economic, technical, and policy uncertainty on the firm's disposition to invest in innovation. This paper borrows primarily from the above three perspectives to emphasize those aspects of the innovation process that are most important for Congress. Their influence will be found in the form of themes that cut across the chapters of the paper.

B. Limitations

As in other fields of endeavor, it is almost an article of faith that our ability to derive benefits from industrial innovation is enhanced by improved knowledge and understanding of the innovation process. There are many difficulties, however, facing theory and research in this area. Innovation is a complex phenomenon incorporating technical, social, and economic dimensions. Innovation processes vary across industries and over time in the same industry, due to differences in structural conditions, incentives, and other important variables. The lack of agreement on definitions and the inherent difficulties in measuring intangible concepts such as innovation result in inconsistent measurements, restricting the comparability of studies and the cumulation of knowledge.

1. THE THEORY OF INNOVATION

Ideally, Government policy for industrial innovation should be based on empirically substantiated theory in the same way that employment policy is based on macroeconomic theories. Such a theory would explain the dynamics of industrial innovation, the ways in which it affects the economy, and the ways in which government can influence the process to achieve its goals. (Pavitt and Walker, p. 15) Unfortunately, such theory as exists is poorly developed and insufficiently tested with empirical results. (Downs and Mohr)

Given the complexity of the innovation process, it is extremely difficult to establish the existence of cause and effect relationships. Correlations have been established between such phenomena as growth of industrial sales and R&D expenditures, but it is impossible to say whether R&D growth causes industrial growth, or vice versa, or whether some third factor—such as good management—causes growth in both industrial sales and R&D expenditures. It is also difficult to attribute an outcome—for example, a successful innovation—to a single antecedent, such as market research.

Since it is inherently dynamic and uncertain, the process of innovation is difficult to incorporate into static theoretical frameworks. For instance, although eminent economists such as Adam Smith, Karl Marx, and Joseph Schumpeter considered the importance of technological innovation, the subject was all but ignored by mainstream economists until recently. They have tended to treat invention and innovation as outside the economic framework, or as "exogenous variables." Changes in technology were generally excluded from consideration in favor of short-term analysis of fluctuations in supply and demand for goods and services. Even when problems of economic growth were considered, "technical progress" was treated as a residual factor, encompassing all contributions to growth other than the traditional factor inputs of labor and capital. (Freeman, p. 17) The original neoclassical theory of the firm assumed that decisions are made by a myriad of small firms, on the basis of universally available and fixed technology, with perfect knowledge of alternatives, for the purposes technology, with perfect knowledge of alternatives, for the purpose of maximizing profits. The discrepancy of these assumptions from much of modern economic reality has prompted the search for a sounder basis for explaining industrial innovation and growth. (See, for example, Klein.)

A final problem that should be mentioned with regard to the theory of innovation is the absence of normative criteria with which to judge the adequacy of the rate and direction of innovation. (NSF, 1976, p. 12) Policymakers and researchers are concerned about whether there is enough (or too much) innovation going on and whether it is directed in the most socially beneficial directions. Innovation is not always a good thing; too much innovation or the wrong kind of innovation can have detrimental effects. Environmental pollution and health hazards resulting from new industrial products and processes are examples of detrimental effects of innovation. Automation that causes short-term unemployment may be another. Innovation frequently creates both positive and negative effects that must be traded off against each other or dealt with in some fashion. Technology assessment attempts to identify and analyze the impacts of technological change, thus aiding decisionmaking on new technology.

2. THE PRACTICALITIES OF INNOVATION RESEARCH

There are also some practical limits to our knowledge of innovation. Innovation is not the unique preserve of any single academic discipline. Researchers representing such varied disciplines as sociology, political science, economics, operations research, industrial engineering, and management science have studied innovation. Although this has its benefits in that multiple dimensions of the innovation process have been investigated, it has its disadvantages to the extent that disciplinary parochialism predominates. Warner has indicated the gaps in knowledge of the diffusion process caused by researchers from various disciplines investigating relatively narrow and non-overlapping aspects of the subject. Moreover, since innovation does not fit neatly within any of the social science disciplines, it is not recognized as a fully orthodox area of specilization by most of them. Thus, the number of researchers contributing to our knowledge of innovation has been fairly limited over the years.

Innovation is also a diffuse activity. It occurs in thousands of industrial firms and other institutions across the country. Relatively few data are collected on innovation activities (other than R&D) on a regular survey basis. Much innovation occurs within industrial firms and information on the process is frequently regarded as proprietary. Some researchers have been allowed access to the records and personnel of innovating firms, but even this does not solve all problems, because the records kept by firms often do not correspond to the definitions used by researchers or government data surveys. Also, there is a certain reluctance to discuss innovation projects that failed, as opposed to those that succeeded. In research that depends on interview data, all the usual problems of recall and objectivity pertain.

Another problem in innovation research is that a large part of innovation consists of ideas and concepts, which are intangible. Unless an idea comes to be embodied in a research project in a company's records, in patent applications, or in new products or processes, it will likely never be studied by innovation researchers. Also, it is difficult to identify innovations because they are, almost by definition, unique.

Because of the difficulties above, much innovation research has been limited to case studies and anecdotal accounts. These are often valuable for the insights they offer into how innovation proceeds in the cases studied, but they are limited in their generalizability. That is, it is hard to say how findings based on a case study of innovation in diesel locomotives will apply to innovation in pharmaceuticals or food mixers. Unfortunately, generalizations in the innovation literature are often based on the experience of a single firm or a particular period. These problems are compounded by a variation of innovation processes and the factors affecting them from industry to industry, product to product, and sector to sector.

3. TAKING STOCK

The limitations to knowledge of innovation processes, although serious, should not be cause for despair. In the last 20 years, considerable progress has been made in improving the understanding of the dynamics of innovation. Moreover, pressures seem to be increasing for Government to make some decisions with respect to innovation and they should be based on the best information and analysis available.

This paper seeks to facilitate the use of existing knowledge of innovation processes by Members of Congress and congressional staff by summarizing those aspects of our knowledge on which there is considerable agreement and which may bear on possible Government actions.

C. Private and Social Returns From Innovation as a Possible Rationale for Government Intervention

Government is concerned with the social impact of industrial innovation. Why, then, should the Federal Government become involved in civilian industrial R&D and innovation, which are largely private sector activities? One reason that has been given with increasing regularity in recent years is that goverment policies in such areas as tax, antitrust, regulation, patents, and procurement have been discouraging industrial innovation. Government policies that are impediments to innovation, some argue, should be reexamined and changed, where possible, to alleviate their negative impacts on innovation. This was the primary rationale for President Carter's Domestic Policy Review of Industrial Innovation. However, many government policies, such as Federal R&D spending, tax deductions for R&D, and the patent system help stimulate innovation. As will be shown later in this paper, little is actually known about the impacts of governmental policies on industrial innovation and what the effects of changes in policy would be. Moreover, since innovation is not always necessarily a good thing (i.e., there can be too much innovation or innovation that is not socially beneficial) it is impossible to say with certainty whether government should attempt to stimulate innovation more than it is currently doing.

In a more theoretical vein, some economic concepts have been developed as criteria for determining when government intervention is appropriate. Economists view the decision to undertake innovation as an investment decision. Economic resources are invested in innovation in the hope of obtaining a return that will pay back the investment and allow a profit. According to economic theory, the cost of investment in any activity should be equal to the benefit society derives from that investment. Such a level of investment will result in the optimal allocation of economic resources. Certain "market imperfections" occur however, that may interfere with the efficient allocation of economic resources as described above. In a market-oriented economy, such market imperfections may be a rationale for initiating or altering government activity.

The *private* return from innovation—that accruing to the innovating firm—may be distinguished from the *social* return from innovation—that accruing to society as a whole. Investment decisions based on the private rate of return from innovation may be different from investment decisions based on the social rate of return. If the benefit to society is to be maximized, investments should be determined by the social rate of return. But in reality, private industrial investments, including R&D and innovation, are based on the private rate of return. The industrial firm's incentive to innovate is based on the private return, not the social return.

In some cases, there may be social costs that do not figure in the private firm's investment decision. A frequently used example is the case of pollution. The decision by a firm to release pollutants into a river imposes costs on persons downstream who have not shared in that decision. As a result, the firm is likely to invest an amount in pollution control that, while satisfactory from its point of view, may be considered inadequate in the broader social context.

On the other hand, the private rate of return from the innovation may be less than the social rate of return from that innovation. Research, development, and innovation are often cited as examples of areas where this situation exists. Benefits from the innovation may accrue to users of the product in the form of savings or increased income that do not figure in the investment decision of the innovating firm, beyond their effect on the firm's return. In this case, the firm may be said to be underinvesting in innovation from society's point of view. (It should be noted that a firm may also overinvest in innovation from society's point of view.) In the case of underinvestment, society may forfeit benefits from innovation due to inadequate private incentives. In such cases, government may intervene to assure that broader social interests are accounted for in the firm's decisionmaking for innovation investment.

Recent research by Mansfield et al. (1977), subsequently validated by Robert Nathan Associates and Foster Assoicates, provided preliminary evidence of high social rates of return relative to private rates of return from innovation in some cases. The initial findings by Mansfield were based on a sample of 17 innovations of average or routine importance in a wide variety of industries, most of which occurred in the 1960's. Additional data were obtained concerning the returns from the innovative activities of one of the Nation's largest firms from 1960 to 1972. Findings from the latter data generally corroborated those from the former.

The social rates of return from the investments in the 17 innovations tended to be high. The median estimated social rate of return was about 56 percent. The private rates of return from the investments in these innovations were much lower than the social rates of return. The median private return, before taxes, was about 25 percent. The riskiness of these investments is evidenced by the variation among the 17 innovations in the private rate of return. The private rate of return before taxes for six of the innovations was less than 10 percent, while for five innovations it was more than 40 percent. In about 30 percent of the cases, the private rate of return was so low that no firm, if it had known the outcome beforehand, would have invested in the innovation, but the social rate of return from the innovation was so high that, from society's point of view, the investment was worthwhile.

Mansfield's findings, as he admits himself, are insufficient to conclude that there is general underinvestment in industrial innovation. For one thing, government intervention existed in Mansfield's cases, in the form of support for basic research and expensing of R&D expenditures for tax purposes, among others. Moreover, it may be argued that in those cases where social benefits are high but private benefits are low, the Government already has a role. Some of these areas include defense, energy, and basic research.

Most economists who have studied social and private returns to industrial innovation feel that it is likely that underinvestment exists. This leaves unanswered, however, the questions of how and in what situations the Government should become involved in innovation and what the socially optimum level of investment in innovation is. Economics and the other policy sciences are still unable to answer these questions. For this reason, and from past experience, it may be unjustified to assume that the Federal Government can make better innovation investment decisions than private industry.

II. Factors Affecting Industrial Innovation

The rate of technological innovation in an industry is influenced by a variety of factors. Mansfield identified some of them, including: the amount of resources devoted to the improvement of the industry's technology, resources devoted by other industries to the improvement of capital goods and other inputs, market structure, legal arrangements, attitudes toward technical change, organization and management of R&D, and the amount and character of R&D performed in universities or other countries. (1968 A, pp. 17–19) The factors affecting innovation are categorized here as economic, technical, and institutional. In reality there is much interaction among the categories. In particular, economic factors largely reflect the other factors, with the added advantage of being easier to measure.

A. Economic Factors

The decision to innovate may be regarded as an investment decision that trades off expected costs and returns. Like other investment decisions, innovation responds to the signals provided by the market in terms of changes in demand and costs of inputs. There are thus two kinds of economic factors affecting innovation: factors that affect the demand for or payoff from innovation and factors that affect the difficulty or cost of innovation. (Nelson and Winter, p. 49).

1. PAYOFF FROM INNOVATION

It is widely accepted that the primary incentive for innovation in industry is expected profit. Mansfield said:

> Econometric studies indicate that the total amount a firm spends on research and development is influenced by the expected profitability of the research and development projects under consideration and that the probability of its accepting a particular research and development project depends on the project's expected returns. Case studies of particular inventions and studies of patent statistics seem to support this view. (1968 A, p. 17)

Often, however, detailed and sophisticated analysis is required to understand where profit opportunities lie in a field of innovation. It is often not easy to identify innovation profit opportunities beforehand, so that expected profit frequently does not correspond with actual profits obtained. Moreover, personal and organizational characteristics may influence a firm's perception of, and response to, profit opportunities. (Discussion of the firm's decisionmaking for R&D and innovation is in Chapter III, Section D.)

Peck's work on the aluminum industry provides some evidence with respect to the relation between innovation and expected profits. He found that the source of innovations in that industry depended on the absolute profitability to the firm of the innovation, the size of these profits relative to firm size, the certainty and immediacy of these profits, the level of R&D resources, and the number of firms. This work, and more recent work by Von Hippel (1979), indicates that the source of innovations in an industry may be determined by relative ability to appropriate these benefits (profits) from the innovation.

Demand for an innovation frequently takes the form of demand for products with improved performance relative to their cost. Nelson, Peck, and Kalachek described this:

> An expansion of demand for a good can be reflected in increased demand for advances which reduce the cost of existing products, or for advances which permit higher performance, or both. The reflection of growing demand generally is an increase in the scale of output of a particular industry. An expansion of industry output clearly provides stimulus to both cost reducing and quality improving advances. The larger the overall market, the greater the potential profit a firm can make from an improvement in efficiency which permits it both to cut costs and to shade prices, and the larger the absolute expansion in sales to be expected from any product improvement. (p. 30)

They noted that the stimulating effect would extend back to the industry's material and equipment suppliers.

Evidence for the importance of demand-pull in explaining patterns of invention was provided by Schmookler. He found that the relative number of patents awarded for capital equipment for different industries was closely related to the past expenditures on capital equipment by those industries. For example, increased demand in the railroad industry for capital equipment seemed to stimulate invention of new and improved railroad capital equipment. Utterback's review of a large number of case studies revealed that 60 to 80 percent of important innovations were in response to market demands and needs; the remainder originated in response to new scientific or technological advances. It may be misleading, however, to assume that market demand is the dominant force in calling forth innovations. As will be discussed later, the supply of new technology and institutional arrangements are also crucial to the innovation process. Moreover, the relative importance of market-pull vs. technology-push is to some extent a chicken-egg problem. Mowery and Rosenberg have criticized the innovation studies that concluded that market demand is the dominant force stimulating innovations.

Given that expected profit is a primary incentive, does investment in innovation have the desired results in terms of innovation and profit? Kamien and Schwartz found substantial evidence that the quest for profit and the devotion of resources to R&D activity positively influence the rate and direction of inventive activity. They also noted that a positive association between sustained R&D programs or innovations and subsequent growth and profitability has been found in a number of studies. (p. 23) The direct average gross rate of return on private R&D expenditures appears to be 30 to 40 percent, which is high compared to alternative investments. (NSF, 1977 C)

On the other hand, there is conflicting evidence about the relationship between levels of profits and innovative activities at a later date. One would expect a positive relationship because R&D is generally funded out of the firm's profits. Pavitt and Walker concluded that the level of corporate earnings appeared to affect the funding of basic research since the decline in corporate earnings during the late 1960's and early 1970's was accompanied by a decline in industrial basic research. The influence of corporate earnings on all R&D activities, however, was not so clear. Studies in the United States and the United Kingdom found no relationship between trends in profit levels and the levels of corporate R&D funding in the late 1950's and 1960's. Thus, Pavitt and Walker concluded, while it appears that successful innovation leads to higher profits, it is not clear that higher profits lead to more innovation. (pp. 38–39) There is evidence, however, that R&D funding levels are set by management in relation to sales levels.

Nelson, Peck, and Kalachek postulated a second kind of demand for innovation: the demand for products which conserve the use of an input which is becoming scarce or costly. They cited arguments that in England, where fuel was scarce and expensive, a much larger percentage of technological advances in the 19th century was aimed at saving fuel than in the United States where fuel was abundant. (pp. 31–32)

More evidence for the importance of innovation in reducing inputs of increasing cost is found in the work of Enos. Enos found in the case of oil refining that technical progress absolutely reduced the requirements for each input. For improvements, he found it possible to predict input savings from trends in input prices and in this phase the scarcest input was saved most. But for major innovations, changes in input proportions bore little relation to trends in input prices—Enos surmised the reason to be that technical factors govern in major innovations.

Nelson, Peck, and Kalachek concluded that:

. . . efforts to advance technology will tend to be drawn toward reducing cost and increasing product performance in industries and classes of products where demand is rising, and toward saving on factors whose relative cost is rising. Since the costs of different kinds of advance may differ this does not necessarily mean that technological advance will be more rapid in large industries, or that factor saving innovation will always be sufficiently strong to offset the growing scarcity of a particular factor—only that allocation of inventive effort will tend to move in these directions. (p. 33)

The response of innovation to changes in relative factor prices, however, is still controversial. (See Binswanger and Ruttan.)

2. COST OF INNOVATION

A firm's propensity to undertake an innovation is determined by the expected cost of innovating, as well as the expected return. An Arthur D. Little, Inc., study of barriers to innovation as perceived by industrial firms found significant concern about payout on plant investments and start up among capital intensive and small companies. This perceived barrier was particularly serious where new processes required new facilities and the abandonment of existing facilities. (p. 20) Some of the determinants of innovation cost are size and complexity of the project, extent of technical advance sought, time available for completion, and the stock of underlying knowledge.

Little information exists about the costs of completed innovation projects undertaken in the private sector with private funding. The most easily obtained costs are those for R&D; however, R&D costs may account for a minor portion of the total costs of an innovation project. Pavitt and Walker, comparing three previous studies (see table 1), found that for five industries in the United States and Canada an average of 47 percent of the total costs of industrial innovation was required for R&D. The range was from 22 to 77 percent. This does not support common wisdom stemming from the earlier "Charpie" report that R&D accounts for about 10 percent of innovation costs. There were differences by industry—R&D being relatively most important in electrical and electronics and least important in chemicals.

TABLE 1.—ESTIMATES OF THE RELATIVE COSTS OF THE STAGES OF INDUSTRIAL INNOVATION

[In percent]

	Chemicals		Machinery, United States	Machinery and transport equipment[1] Canada	Electronics, United States	Electrical, Canada
	United States	Canada				
Research and development	43	22	47	43	51	77
Tooling, manufacturing facilities and startup	50	70	42	51	43	21
Marketing startup and other expenses	7	8	11	6	6	2
Total	100	100	100	100	100	100

[1] Excluding aircraft.

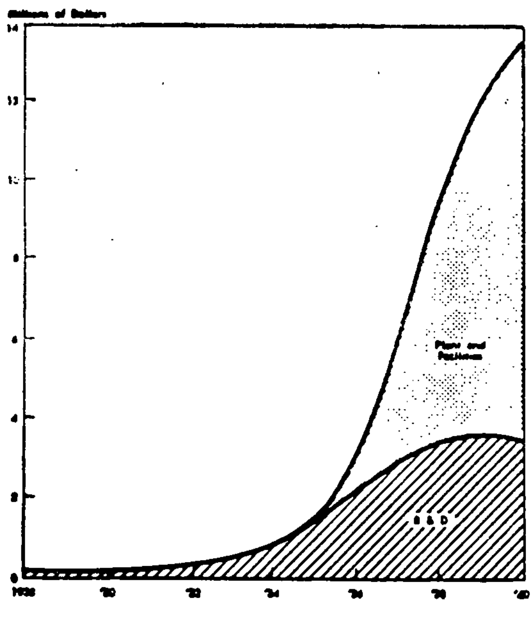
Sources: United States: E. Mansfield et al., "Pesearch and Innovation in the Modern Corporation" (MacMillan Press, New York, 1971) ch. 6. Canada: H. Stead, "The Cost of Technological Innovation", Research Policy 5(1976)2.

It should be noted that a unit of advance in one technology or industry may cost more than in another. For instance, large expenditures may be necessary in aircraft or steel for an amount of advance that would cost much less in scientific instruments.

Mansfield et al. recently analyzed the distribution of costs in the development process (the activities leading to introduction of a new product, excluding basic research) for 56 polymer development projects. Most development costs were spent on four activities—pilot plant, applications research, market development, and bench scale work. About 50 percent of the total costs went for pilot plant work, about 19 percent for applications research, about 14 percent for market development and about 12 percent for bench scale work. There was considerable variation in the distribution of costs between projects; some projects, for example, required no market development at all. There may be change over time in the importance of various development activities. For example, pilot plant work may have become less important in chemical development. (Mansfield, et. al., 1977, p. 199)

Nelson, Peck, and Kalachek demonstrated the dramatic cost escalation in the later stages of innovative activity, based on Du Pont's expenditures for Nylon. (See figure 2.)

FIGURE 2.—Du Pont's Annual Investment in Nylon, 1928–40



They said:

The first polymers were produced and shown to be useful for textile fibers in 1934. Up to that point, Du Pont had invested only about $1 million in R&D. The large expenses occurred later. Ways had to be found to process the polymer into filaments and to spin them into useful fibers. Some of this work could be done relatively inexpensively in the laboratory, but difficulties in extrapolating the results of some small-scale reactions made it necessary to build and experiment with large scale equipment. Between 1934 and 1939, the year that large-scale production of nylon stockings was begun, Du Pont invested $26 million; $5 million more in R&D, and $21 million in plant. (p. 92)

Few data exist on the total costs of specific innovations. This is regarded as proprietary information and may not be readily determinable even by the innovating firm. Figures are available for a few projects, but they are not meaningful given different definitions and the change in dollar values over time. Moreover, it is the distribution of costs over the life of an innovation project (e.g., for R&D, pilot plant, etc.) that is of interest.

As pointed out by Mansfield, the absolute costs of innovation may not be as important in the innovation process as the cost of innovation relative to the assets of the firm or industry undertaking the innovation. In the chemical industry, according to Manfield, the costs of innovation are unusually high relative to the assets of the firms; therefore the largest firm, Du Pont, plays a major role in the introduction of innovations relative to smaller firms.

Freeman supported this view, saying:

> . . . the higher the development and associated innovation costs, the greater the advantage to the larger scale producer. . . . The development, design and test costs are very high for new generations of equipment and they are an absolute threshold which must be met by any firm which wishes to compete, irrespective of its sales volume. The predominance of the giant corporation in innovation in many branches of industry is quite understandable in the light of these considerations. . . . (pp. 219–220)

Mansfield's recent findings indicate that, all other things being equal, the development cost for a polymer seems to decrease, on the average, by about 1⅓ percent for every year of additional R&D experience in the area on the part of the firm. Moreover, the percentage of total innovation costs devoted to R&D tends to decrease as the firm gains more and more innovation experience. Thus, experience in a particular area of R&D helps make firms more efficient at innovation in that area.

Nelson, Peck, and Kalachek suggested the existence of a trade-off between research to build the scientific base of an industry and the later stages of development work. They suggested that resources devoted to building the scientific base would pay off by reducing the cost of later innovation work. In a similar vein, Freeman pointed out that as the scientific understanding in an industry increases, there is less need for empiricism in the pilot plant stage because more reliable extrapolations can be made from small-scale experiments to production-line conditions. Hamberg also noted that R&D costs less in industries that have a well-developed scientific base.

3. INTERNATIONAL TECHNOLOGY TRANSFER

Recently there has been some concern about international technology transfer and its effects on U.S. economic welfare and technological position. Some analysts have argued that through exports, foreign direct investment, and licensing, U.S. firms are diffusing their technology throughout the world, where it may be copied and sold for lower prices, thus increasing competition for American industry. It has been argued that through the transfer overseas of American technology, the United States is losing the position of technological superiority it has had in many product lines since World War II. There have been calls for government to place controls on international technology transfer for these reasons. It is frequently not realized, however, that the possibility of a firm's exporting, making foreign investments, or selling licenses may induce it to engage in R&D programs that would not be economical if the U.S. market were the only one considered. It has been hypothesized that the possibility of international technology transfer actually works to increase U.S. technological innovation.

In an effort to investigate this hypothesis, Mansfield, Romeo, and Wagner have provided what appears to be the first systematic evidence on the effects of foreign trade on U.S. R&D activities. Based on a sample of 30 firms, they found that about 30 percent of an R&D project's returns, on the average, were expected to come from foreign markets or foreign utilization. There was a great deal of variation among firms, however; some firms expected zero percent of returns to come from foreign sales or utilization, while some firms expected as much as 60 percent to come from such sources. This variation appears to be due to variation in the amount of overseas business conducted by the firms. The relative importance of foreign markets and utilization in the returns from a firm's R&D program was directly related to the extent to which it depended on foreign sources for its current sales. Holding constant a firm's percentage of sales from abroad, the relative importance of foreign markets and utilization in the returns from a firm's R&D program was greater in more research-intensive firms.

Based on data from 10 of the firms (all in the chemical industry), it appears that research projects have a somewhat larger share of their returns come from abroad than development projects. This seems reasonable, since the results of research projects are probably less specific and thus may be applied in foreign markets as well as domestic markets. Foreign returns are expected to be most important for R&D projects aimed at new products—accounting for about 40 percent of the return on an average. According to executives from the firms, the principal reason a larger share of the returns from new product R&D is expected to come from foreign markets is that the firms are hesitant to send their process technology overseas, since it is more difficult to control.

These preliminary data indicate that much of U.S. R&D is done with the expectation that a considerable portion of the returns will come from abroad. Thus international technology transfer appears to act as an incentive to U.S. R&D. This would lead one to expect that if international technology transfer opportunities did not exist, then an important incentive to conduct R&D would be lost. Mansfield's data indicate that firms would reduce their R&D spending by 12 to 15 percent if they could not utilize any new technology abroad in foreign subsidiaries. They would reduce their R&D spending by 16 to 26 percent if foreign subsidiaries and all other means of international technology transfer were cut off. The percentage cut for product R&D would be about 35 percent, while for process R&D it would be about 5 percent. This is consistent with the finding that a much larger share of the returns from product R&D is expected to come from abroad. Analysis revealed that relatively little difference would occur in the size of reductions for basic research, applied research, and development.

B. Technical Factors

Although economic factors are crucial in the innovation process, they alone do not govern it. The supply of new technology is also necessary. Sometimes technical factors are preeminent in stimulating technological innovation. As stated by Pavitt and Walker:

> Very significant innovations have grown out of new scientific discoveries (e.g., nuclear power), and some have created their own demand (e.g., computers); and need-stimulated innovations still require the application of known and of newly created scientific and technological knowledge. . . . (p. 21)

1. THE SCIENCE BASE

Advances in science are important components of the "technical" factor. It is frequently claimed that the rate and character of scientific advances have significantly affected the rate and character of technological advances, especially in recent times. This is said to be particularly so for major advances in technology, as opposed to minor improvements. (Mansfield, 1968 A, pp. 11–12) Specific cases have been cited where basic research has led to major technological advances, such as transistors, nylon, dacron, hybrid corn, and radar.

In some cases the lack of scientific knowledge has held up the invention and introduction of important products. Nelson, Peck, and Kalachek argued that:

> . . . there was strong demand for products such as antiseptics and the telephone long before their invention. Had they been invented years before, there is little doubt that they would have been profitable. In both cases there is no question but practical experience played a role in posing the problem and in suggesting certain aspects of the solution. But in each, an essential part of the thinking which triggered the efforts at invention and was applied to solve the problem involved scientific understanding which did not exist before; the germ theory of infection in the one case, the theory of electromagnetism in the other. (p. 39)

In the 20th century whole industries based on science have arisen, such as the chemical, electronics, and aviation industries. Science appears to be necessary to provide the basis for new industries of the future which will replace older industries of lower productivity. Science is sometimes pictured as the "engine" of technology, without which technological progress would eventually slow down and stagnate.

The science base underlying an industry's technology may explain some of the differences in rates of technological change among industries. Nelson, Peck, and Kalachek argued that major technological advances come more easily in the science-based industries because of the large and continuing effort they put into basic and exploratory research. (p. 43) Hamberg expressed the opinion that when an industry draws upon a well-developed basic science, R&D costs are lower. Nelson explained why this should be so:

> In the activity of invention, as in most goal-directed activities, the actor has a number of alternative paths among which he must choose. The greater his knowledge of the relevant fields, the more likely he will be eventually to find a satisfactory path, and the fewer the expected number of tried alternatives before a satisfactory one is found. Thus, the greater the underlying knowledge, the lower the expected cost of making any particular invention. (p. 152)

The evidence on this issue, however, is inconclusive. While the trend may be positive, the actual fraction of innovation due directly to basic research may still be low. Moreover, the declining trend in industrial basic scientific research indicates that the relation of science to innovation is heavily conditioned by economic, policy, managerial, and other factors. (Nason, et al.)

Since the middle 1960's there have been several studies attempting to connect basic scientific research with industrial innovation. In 1965, Price, based on an examination of citations in scientific and technological journals, concluded that science and technology progressed largely independently of one another. Project Hindsight, sponsored by the Department of Defense, found basic science inputs to be of little importance to technological developments. However, this may have been due to the short period studied. Two other studies—TRACES and Interactions of Science and Technology in the Innovative Process—found basic research to be crucial to the innovations studied. TRACES found that 30 years, on average, elapsed between basic research events and their technological application. A 1974 study by Gibbons and Johnston found that, of 900 knowledge inputs to 30 innovations, more than one-third of those inputs from outside the firm were from scientific literature. That study concluded that basic scientific research contributed to industrial innovation, both directly—through the transfer of information relevant to specific innovations via scientific literature or contact with basic research scientists—and indirectly through the primary and continuing education of industrial engineers.

A recent study of citation patterns in patent applications for prostaglandins and gas lasers found strong ties to the scientific literature. (Carpenter and Narin) Eighty percent of the references from prostaglandin patents to all sources (patents, scientific journal articles, and miscellaneous sources) were to papers in scientific journals and about one-third of the references in gas laser patents were to scientific journals. Moreover, the scientific literature cited was relatively recent:

> The median age of the cited papers from the prostaglandin patents was about six years, two years older than the median age for papers cited by typical chemical papers. The gas laser patents cited literature with a median age of only three years, two years younger than the median age of papers cited by typical physics papers. (p. iv)

Innovation researcher Thomas Allen has suggested that ordinarily a long time lapse occurs between a scientific advance and a technological advance that utilizes it. However, this delay may be significantly shortened under certain conditions—specifically, when a technology has advanced to a limit at which an improved understanding of the basic science involved is required; when the problem is communicated by the technologists to basic scientists in terms of a basic research problem; when the scientists attack and resolve the problem; and when the solution is passed back into the technology immediately. Thus, direct and immediate application of basic research to technology seems to occur when the technological problem is the driving force and can be translated into an interesting and researchable basic science problem. (pp. 52–53)

A large part of the effect of basic research upon industrial innovation is made through the education of industrial scientists and engineers. (Haeffner, Gibbons, and Johnston) Much of the flow of scientific and technical information into the industrial firm is "person-embodied."

Among the most effective channels are the movement of graduates into industry and the communication of a teacher to students. (Shimshoni)

Gibbons and Johnston, writing in Europe, where there are distinct educational programs oriented towards industry and academia, found that the type of education that predominates in an industry partly determines the types of innovations that are undertaken. Those with predominantly industry-oriented education are limited to seeking solutions to problems that lie within their educational training or industrial experience, while those with predominantly academic training have the ability to try a wider range of solutions. (pp. 237–238)

2. TECHNOLOGICAL FACTORS

Although they are frequently considered together, it is important to distinguish scientific and technological inputs to innovation. Rosenberg emphasized that technology is to a large extent "self-contained" in the sense that it exploits knowledge which has been produced within the technological realm and not imported from the scientific world. Such knowledge is often a by-product of manufacturing processes. Rosenberg said:

> Much of the most important work of engineers has involved the design and development of products with certain performance specifications and without the guidance of systematized scientific knowledge. In aerodynamics and fluid mechanics, for example, engineers have routinely produced information sufficient for a safe and workable solution to some technical problem long before scientific understanding was achieved. . . . Just as the attempt to understand the factors determining the performance of the steam engine historically gave rise to the laws of thermodynamics, so has the attempt to understand the principles determining the operation of *already-existing* technology given rise to the development of further new scientific knowledge. Thus, the relation between the realms of science and technology is not a simple and linear one of causation, but includes much more intricate loops and feedbacks than is generally recognized. (1976, pp. 23–24)

Nelson and Winter also emphasized the importance of technological factors in explaining differential rates of innovation. They suggested the proposition that "research and development activity is more powerful when directed toward the technologies of certain industries than toward the technologies of others; therefore, the disparities in rates of technical progress reflect some kind of innate differences in ability to advance efficiently the different kinds of technologies." (p. 45)

Nelson and Winter referred to technological "trajectories" to describe the fact that technological progress seems to have a certain dynamic of its own. They explained:

> . . . Particularly in industries where technological advance is very rapid, advances seem to follow advances in a way that appears somewhat "inevitable" and certainly not fine tuned to the changing demand and cost conditions. Rosenberg talks of "technological imperatives" as guiding the evolution of certain technologies; bottlenecks in connected processes, obvious weak spots in products, clear targets for improvement, etc. . . . (p. 56)

Hughes made use of similar concepts—such as "critical problems" and "bottlenecks" in technology in his biographies of major inventors.

In many cases trajectories are specific to a particular technology or broad group of technologies. A technological trajectory refers to engineers' beliefs about what kind of change is feasible or worth attempting. Nelson and Winter elaborated:

> . . . For example, the advent of the DC-3 aircraft in the 1930's defined a particular technological regime; metal skin, low wing, piston powered planes. Engineers had some strong notions regarding the potential of this regime. For more than two decades innovation in aircraft design essentially involved better exploitation of this potential; improving the engines, enlargening the planes, making them more efficient. . . . In many cases the promising trajectories and strategies for technological advance, within a given regime, are associated with imrovements of major components or aspects thereof. In aviation, engineers can work on improving the thrust-weight ratio of engines, or on increasing the lift-drag ratio of airframes. General theoretical understanding provides clues as to how to proceed. . . . (p. 57)

There also appear to be certain generic trajectories that apply to a broad range of technologies. Two such trajectories that have existed for centuries are exploitation of economies of scale and mechanization of operations that have been done by hand. Two new trajectories opened up in the 20th century; (1) The exploitation of understanding of electricity and the resulting creation and improvement of electrical and later electronic components, and (2) similar developments regarding chemical technologies.

Nelson and Winter discussed some of the implications of these trajectories for industry:

> . . . improvements in ability to understand electrical phenomena and growing experience with electrical and electronic equipment led to a substitution of these kinds of components for others. And technologies that had many and important electronic components were better able to benefit from the improvements in these components than other technologies. It is apparent that industries differ significantly in the extent to which they can exploit the prevailing general natural trajectories, and that these differences influence the rise and fall of different industries and technologies. (p. 59)

Thus, technological factors, broadly defined, are important influences on innovation and they vary significantly from industry to industry.

C. Institutional Factors

Institutional factors also affect industrial innovation. Markets, governments, industries, and firms are some of the institutions involved in the process of industrial innovation. Each institution has its own characteristics that affect the outcome of the process. For example, although innovation responds to market signals to a large extent, markets do not always allocate resources in socially optimal ways. In these cases governments may intervene and when they do, political considerations inevitably come into play.

The structure and motivation of industries and firms affect their willingness and ability to undertake R&D and innovation. Moreover, not only must the innovating firm be considered, but so must suppliers and customers, sources of finance, sources of scientific and technical knowledge and other institutions. There is a system of institutions that interact in the introduction and application of innovations. For the innovation process to proceed smoothly, all the components of the system must act in harmony. As indicated by Nelson, Peck, and Kalacheck:

> In some cases no real problem exists; thus the success of the catalytic cracking process depended almost entirely on changes internal to the adapting com-

pany. Sometimes, however, there may be fragmentation of authority. The effective introduction of prefabrication in the building industry thus may require a revision of building costs by local governments and modification of behavior by architects, structural engineers, contractors, and labor unions, with the incentives for any one group to change being relatively small until the other groups change their practices. . . . (pp. 100–101)

The institutions involved in innovation vary significantly from sector to sector; for instance, the institutions handling innovations in the public sector are quite different from those in the manufacturing sector. Such institutional differences partly account for differences in the rate and direction of innovation in these sectors, but just how is not well understood. The diffuse performance criteria by which public agency managers are judged may be a deterrent to innovation. (Roessner, 1975) The importance of institutional factors to innovation in such areas as housing has been underscored in case studies. (Strassman)

Obstruction of labor unions to technological change has been a common charge. Carter and Williams, however, found that in Great Britain in the early 1950's, labor acceptance of change, rather than resistance, was the rule, except in depressed industries. Where there had been a history of labor trouble on different issues, there was more likely to be resistance to technological change. Firms might forestall labor resistance by going slow with innovations, but this did not appear to be a major problem. Mansfield, in the United States in the 1960's, found that willing acceptance of technological changes was the most frequent union policy, and outright opposition to change, although not rare, was found in only a small proportion of cases. (1967A, p. 150) Since labor resistance to technological change is motivated by a fear of unemployment, it may wax and wane with economic conditions. A 1973 study of perceived barriers to industrial innovation by Arthur D. Little, Inc., noted:

Resistance on the part of labor unions does not seem to constitute an important perceived barrier to innovation. None of our industry respondents raised this issue. (However, industries with known labor-related barriers to innovation were not included in our sample. . . .) (p. 21)

A 1979 study by McLaughlin concluded that the most common response of U.S. labor unions to the introduction of new technology is willing acceptance. The second most common response is opposition, followed by adjustment or willing acceptance. The organizational effects on corporations dealing with labor unions may discourage innovation indirectly.

Institutional arrangements may be a major obstacle to innovation in many areas such as local governments, fragmented industries, housing, and consumer products. There have been calls for institutional reforms and completely new types of institutions to stimulate innovation. Institutional rigidities and inflexibilities may tend to be correlated with the age of the industry or product. (Abernathy and Utterback) Organization theory would tend to support this claim. (Burns and Stalker)

Institutional factors are certainly important in determining the rate and direction of innovative activity and must be taken into account in any consideration of policy action. They are probably less well understood than the economic and technological factors.

D. Summary

Industrial innovation responds to economic forces, and in doing so helps make the economy flexible and responsive to changing conditions of demand and input costs. But the response does not happen automatically because the innovation process is also guided by technical and institutional factors.

Innovation depends on the perceptions, knowledge, skills, and capabilities of individuals and organizations. Economic signals are perceived by corporate executives who may decide to invest more in R&D for new products or production processes. Research and development are heavily influenced by technical factors, especially in the early stages. Economic considerations are always there implicitly, but use of specific economic variables in making R&D decisions is made increasingly as one moves into the later stages of R&D. The technical part of the innovation process has its own laws which guide its direction and determine how rapidly innovation can respond to economic signals. Institutional factors must also be conducive to innovation and there is always the element of chance.

Congress needs to be aware of the problems and complications that may arise in attempting to force technological change, as well as the potential for meeting national needs. A graphic analogy is provided by Alexander, who warns that pressure to force technological change "must be applied with knowledge, prudence, and patience." Industries and technologies, he said:

> . . . have their own natural time scales for change, the pace being determined by the workings of such sequences as the depreciation and retirement of capital equipment and the research, development, test, scale-up, and production cycle. Attempting to force change too rapidly . . . is like trying to propel a boat beyond its own inherent hull speed, as established by the laws of hydrodynamics. The result is scant additional progress, lots of waves, noise, and wasted energy—and in the extreme, destruction of the boat. (p. 141)

This is not to say that Congress will not be able to stimulate industrial innovation, but merely to assert that to obtain optimum benefits from the industrial innovation system requires working with it, not against it.

III. Risk and Uncertainty

Risk and uncertainty are inherent characteristics of the innovation process, stemming from its essentially "new" nature. Uncertainty may be the single most critical aspect of industrial innovation.

Innovation is a process of elimination. Most projects are scrapped before they reach the development stage. Although risk and uncertainty are especially high in the early stages (perhaps less than 10 percent of submitted ideas pass the initial screening), they are associated with all phases of innovation activity and frequently remain at substantial levels even when the new product or process is introduced to commercial use. According to Freeman, the conventional wisdom of R&D management is that the "success" ratio is one project in 10 or even 1 in 100. (p. 222) A study by Mansfield showed that for every 100 projects that were begun, 57 were completed technically, 31 of this number were commercialized, and only 12 of the 31 were market successes. (1971, p. 62) One author said that of product ideas received by a firm, only about 0.5 to 3.5 percent result in some form of profitable return on investment. (Haeffner) Many other such estimates of success and failure rates have been made.

Such generalizations about the proportion of projects that fail, however, may be misleading because they are often unclear about the criterion of failure they are using and the phase of the innovation process to which they are referring. "Failure" may mean that a project was terminated at any stage of the process from basic research through development or initial marketing. Termination is much more common in the early phases than the late ones, although it is still frequent in these phases. Moreover, the criteria for success may differ from firm to firm. An innovation terminated by one firm because of disappointing sales may be continued by a firm that does not seek as high a level of sales. Nevertheless, the main point remains valid: Innovation is a process of elimination and the chance of any individual project making it through to the market and succeeding there is slim.

A recent study of 200 innovations that passed the initial screening, but failed subsequently, found that once past the initial screening little weeding out was done until the project entered the relatively expensive later stages. Almost three-quarters of the innovations made it into pilot test before being discontinued. More innovations—23 percent—failed in pilot test than in any other stage. The second largest number of innovations—19 percent—was dropped in the last and most expensive stage, production installation. The marketplace presented the greatest risk. Uncontrollable market factors and limited sales potential accounted for many failures, but poor management accounted for many also. (Myers and Sweezy)

Risk and uncertainty are terms used to refer to the high chance of failure that exists in innovation. They represent different degrees of a chance of failure. Risk is the *probability* of failure and as such can be calculated by applying statistical methods to existing bodies of data. Thus, if it is similar to those of the past, one may calculate that project X has a 10 percent chance of succeeding and make a rational decision on whether to proceed. Uncertainty, on the other hand, describes situations where the probability of success cannot be calculated. In such cases, decisions must be made on other than purely rational bases. Uncertainty, rather than risk, dominates the innovation process because of its discontinuity with the past.

In general, uncertainty is caused by imperfect information about present circumstances and about what will happen in the future. The degree of uncertainty tends to increase with the length of time into the future, because with more time there is a greater possibility of events occurring that could adversely affect the project. For this reason, the success of a project scheduled for introduction in one year may be less uncertain than one scheduled for introduction in 5 years. The degree of uncertainty also generally increases with the degree of technological advance that is sought in a project. Thus, basic scientific research and radical product innovations represent high degrees of uncertainty, while modification of products and processes and product differentiation ("model" changes) represent little uncertainty.

A. *Types of Uncertainty*

Uncertainty associated with innovation may be due to a variety of factors: technology, production, suppliers, customers; third parties such as labor, government, and public interest groups; and timing. There is no agreement on which type of uncertainty is greatest, as it may depend on the specific case. Although market uncertainty often seems greater than technological uncertainty, they are closely related and tend to be reduced in tandem as research progresses to development.

Some uncertainty may be due to lack of knowledge of what the competition is doing. If Firm B introduces a better product before or after Firm A introduces one, it will likely mean failure for Firm A's new product. Thus, the technical and commercial success of competitors may affect the outcome of each innovation attempt. This type of uncertainty does not exist in all situations, but there are other sources of uncertainty even when this one does not exist. Uncertainty may be classified as technical uncertainty, market uncertainty, and general business uncertainty.

1. GENERAL BUSINESS UNCERTAINTY

General business uncertainty refers to lack of knowledge about future economic conditions and business environment. To account for this type of uncertainty, a discount rate is generally applied to estimated future income and expenditures from proposed projects. Although it applies to all decisions about the future, general business uncertainty has a disproportionate impact on innovation investments to the extent that they have a longer time horizon.

2. TECHNICAL UNCERTAINTY

Discussing technical uncertainty, Freeman made an important point:

> Technical uncertainty is not merely a matter of "work" or "not work," although this is, of course, decisive for success. . . . Much more usually it is a question of *degree*—of standards of performance under various operating conditions and at what *cost*. The uncertainty lies in the extent to which the innovation will satisfy a variety of technical criteria without increased costs of development, production, or operation. (p. 224)

One of the purposes of R&D and test production is to reduce the technical uncertainty. Some may remain, however, even in the early stages of commercial introduction. Occasionally, technical bugs may lead to serious setbacks some time after commercial launch. Some expensive and well-known examples are the Comet jet airliner and Du Pont's Corfam. (Freeman, p. 224)

3. MARKET UNCERTAINTY

Market uncertainty has to do with the market for the innovation being introduced. The questions involve how great the demand will be for the new product as reflected in sales and sales growth, and how the innovation will affect the innovating firm's competitive position. Market uncertainty is, of course, closely tied to technical uncertainty. If the product cannot be manufactured at a low enough cost, perhaps because of engineering design, the price that will have to be charged may reduce sales below an acceptable level. If the innovation is completely new, there may be no competing products and the uncertainty may be whether sufficient demand exists or can be created. Market uncertainty was the most important barrier to innovation perceived by industry, according to a 1973 study by A. D. Little. This may be due to the fact that market uncertainty is the area about which top management will likely have the greatest interest and knowledge.

4. POLICY UNCERTAINTY

Another source of uncertainty in innovation is Government policy. Recently industrial leaders, for example, have been complaining that one of the most difficult aspects of government regulation with which they must deal is the uncertainty about what new regulations may be promulgated in the future, what the standards will be, and how thoroughly they will be enforced. This is particularly problematic in times of rapid change in policy.

B. Innovation as a Process of Uncertainty Reduction

Innovation may be regarded as a process of uncertainty reduction. Uncertainty tends to be highest at the basic research end of the spectrum of innovation activity. Each succeeding stage produces information that allows the firm to estimate more accurately the project's technical and economic potential. Nelson, Peck, and Kalachek described this strategy:

> . . . the typical R&D strategy of the business firm is to avoid major financial commitments to untried ideas; rather, it seeks to obtain knowledge and thus to reduce the uncertainty surrounding the idea by investing relatively small sums in additional research. At each stage in the processs, the company spends money to generate the knowledge necessary for deciding whether to proceed or retrench. As the idea proceeds from design concept to laboratory experimentation to prototype construction to production of limited batches, the investment becomes larger, and is undertaken only if the evidence increasingly points to the probability of profitable production. (p. 174)

Private industry may tend to be more conservative than Government in decisions to proceed with innovation. Often major developments in military R&D are initiated while considerable uncertainties still remain. Consequently, early estimates of cost and value are notoriously inaccurate. In commercial developments there appear to be fewer such examples, perhaps because decisions to go ahead with development are made more conservatively. (Ibid., p. 93) This may also be due to private sector reluctance to release data on its big fiascos.

Rosenberg attributed much of American success in high technology areas to conservative commercial judgment. He argued:

> There is a fundamental difference between technological success and commercial success. Indeed, I believe that America's success in the high technology area has been due in no small measure to the exercise, by private industry, of a shrewd commercial judgment concerning adoption decisions—i.e., deciding when a new technology has reached the point of commercial feasibility and profitability. (1976, p. 32)

Although R&D may help reduce uncertainty about the technology, some uncertainty remains throughout the process and even after the product has been introduced to the market. Although R&D and pilot operations can demonstrate technical feasibility, the cost estimates they provide may not be accurate. The demand for the product and the uses to which customers will put it are often extremely difficult to predict. The only way to resolve these uncertainties is through trial production and market test. Potential users may be experimenting with the new product in this early use period. This provides feedback to management and engineers, who may redesign the product or alter operations. Thus, even the early use period may be viewed as an exploratory learning experience, rather than as a long-term committal. (Nelson, Peck, and Kalachek, p. 96)

Success in the market is frequently regarded as the real test of the innovation process. As a process of uncertainty reduction, however, this "weeding out" serves a useful function if it reveals, before the expenditure of large sums of money, that the concept is technically unfeasible or economically unattractive. Nelson, Peck, and Kalachek noted:

> Many writers have commented on the apparent waste in the technological change process: a large number of projects never result in anything useful, duplication of effort is involved in competitive and parallel approaches when only one solution is needed, many people and organizations resist new technology.
>
> Yet sequential decisionmaking in situations of great uncertainty which can be reduced, either by small-scale efforts or by waiting, is rational both from the point of view of individuals and the economy as a whole. If waste is involved in duplicate efforts, it is also involved in commitment too early to an inferior approach. If there are economic costs of delay in accepting superior technology, there also are costs in accepting new technology that turns out to be uneconomic. (pp. 108–109)

This is not to say that the number of failures can not profitably be reduced through better management and market research.

C. Difficulty of Prediction

A key aspect of the uncertainty in the innovation process is the inability to predict factors needed to make decisions on whether to pursue an innovation project.

1. PREDICTING TECHNICAL FACTORS

Although both technical and market success are difficult to predict, it is widely agreed that it is easier to predict the former than the latter, Mansfield has researched the predictions of technical completion made by firms. His findings indicate that both the cost and the time required to complete R&D projects tend to be underestimated beforehand and the degree of underestimation tends to increase with the degree of technological advance involved in the project. His work shows that substantial overruns occur with respect to cost and time in civilian as well as in military work. Freeman has commented upon Mansfield's findings:

> . . . [the] estimating errors cannot be attributed to inexperience, as the firms which he investigated had long experience of project estimation and innovation, and were among the leading R. & D. performers in the U.S. in-

dustry. The results do, however, suggest that there is some trade-off between cost and time as the average overrun in military projects was much greater with respect to cost than time, whilst the opposite was true of civil projects, both in the USA and the UK. (p. 229)

There is also a notable bias toward optimism in technical prediction. For many of the important innovations studied by Freeman, the development time was much longer than anticipated and the development costs were frequently much higher. It is possible that scientists and engineers consciously bias their estimates in an optimistic fashion to secure corporate support for the project. Mansfield's interviews indicated that this indeed occurs. A study by Thomas in 1970 also found that estimates were consciously biased optimistically to make projects look attractive to the firm. The rationale was that potentially valuable projects otherwise would not survive inflexible evaluative criteria. (Freeman, p. 231)

2. PREDICTING MARKET FACTORS

It is widely agreed that market factors such as market size, sales, and profits are difficult to predict. In fact the early estimates of future markets for many major innovations have been "wildly inaccurate." According to Freeman:

. . . Almost every major innovation in [the electronics industry and in synthetic materials] was hopelessly underestimated in its early stages, including polyethylene, PVC [polyvinylchloride] and synthetic rubber in the materials field, and the computer, the transistor and numerical control in electronics. . . . But there are also examples of gross overoptimism, for example in relation to the fuel cell, the airship, "Ardil" (the synthetic fibre), and the IBM "STRETCH" computer. (pp. 233–234)

Beardsley and Mansfield recently published a study of the accuracy of industrial forecasts of the profitability of innovations, based on the records of a large firm for the years 1960–1964. They found large forecasting errors for both new products and processes. Moreover, it took four or five years after the development of the innovation for the firm to be able to estimate reasonably well the profits that were ultimately obtained. The firm tended to underestimate the profitability of very profitable innovations and to overestimate the profitability of relatively unprofitable innovations. On the average, the firm underestimated the profitability of innovations. Despite its limitations, the study underscores the inherent uncertainty involved in estimating the profitability of innovation.

Why are market factors so difficult to predict? A firm's decision to market an improved product will depend upon additional sales anticipated, among other things. Whether the additional sales materialize will depend upon how customers react to the improved product and the actions competitors take. Although modern marketing has made much progress, relatively little remains known about the behavior of customers in the acceptance of innovations (Robertson, p. 21), and economic theory is unable to predict the reactions of oligopolistic competitors in the face of innovation. Nor can trends in legislation that may affect new products be safely predicted. The prediction of future sales revenue and possible profit depends not only on forecasting total quantity which can be sold, but also on forecasting future costs of production and price levels. Moreover, the market launch and growth of sales may be spread over 20 years and a great many things can change during this time. (Freeman, p. 232) Thus, the great number of complexly interacting factors that need to be taken into account and the lengthy periods of time involved make prediction of market factors for innovative products difficult.

D. Effects on Innovation Decisionmaking

The great uncertainty surrounding technical and market aspects of the innovation process explains much of the character of decision-making for innovation within the firm. Although actual decision processes and techniques vary from firm to firm and from industry to industry, there are some common characteristics, which will be discussed here. This discussion pertains primarily to the generation phases of innovation—e.g., R&D, pilot plant and commercialization—but applies generally to adoption decisionmaking as well.

Economists have tended to view innovation decisionmaking in an idealized manner, where the decisionmaker calculates:

(1) The probable costs of development, production, launch, and use or marketing of the innovation and the approximate timing of these expenditures;

(2) The probable future income stream arising from the sale or use of the innovation and its timing; and

(3) The probability of success, technically and commercially. (Freeman, p. 227)

The profits from the innovation are calculated as an expected value or a rate of return to the investment in the innovation project, discounted for the time required to obtain the profits. The discounted value or rate of return is then compared to that for other investments the firm may make. The firm chooses the investment with the highest discounted value or rate of return.

Empirical research on innovation decisionmaking in industrial firms, although limited, does not support the idealized view. This is largely because the estimates of costs, income, and probability of success are often wrong, especially in more innovative projects and in the early stages of innovation. Innovation decisionmaking in the industrial firm appears to be sequential, to involve multiple evaluative criteria, and to be largely governed by "rules of thumb" rather than precise calculations of risk and reward. Freeman characterized it as "groping and experimental." He continued:

> The firm attempts to use R&D and other scientific and technical services to reduce the uncertainty which confronts it. But the nature of R&D is such that technical and market uncertainties remain despite its best efforts. Some types of R&D may indeed increase the uncertainty. Consequently, a high degree of instability will remain and decisionmaking in the firm will continue to resemble a process of "muddling through" rather than the ordered, rational calculation beloved of neo-classical theory. (p. 40)

To some extent the "rules of thumb" and "muddling through" may be regarded as approximations to economic rationality.

Empirical studies reviewed by Clarke suggest that decisonmaking tends to be sequential and that, although the same criteria tend to be used in all phases of project evaluation, the weights attached to them vary as the innovation progresses. As the potential magnitude of a project becomes larger, the organizational level of the decisionmakers goes up and there is a resultant shift in emphasis towards economic criteria. Thus, market potential would have a low weighting in decisions on exporatory research and a high rating in decisions for pilot plant. On the other hand, the chance of technical success would have a high rating in early stages and presumably would be of less concern as more technical uncertainty is removed. (p. 18) Exploratory projects may be decided upon by the researcher and his or her supervisor on the basis of chance of technical success. Decisions later in the innovation process involve large expenditures and require decisions by top management with information from the marketing, financial, manufacturing, and R&D departments.

Although most firms report using some quantitative criteria for project selection and evaluation, there is little use of the available formal mathematical models. Moreover, it appears that industrial people do not take the quantitative estimates of expected value or rate of return very seriously. Firms say this is because present models do not sufficiently take into account the sequential nature of decisionmaking in innovative activities, the uncertainties involved, the multiple criteria needed to evaluate R&D, and the lack of sophistication of many managers in the use of models. (Clarke)

A survey of 27 large companies provided some evidence that increasingly sophisticated project evaluation techniques are employed as the innovation project progresses. For exploratory research the selection process was found to be generally simple and unsophisticated, while for high risk business development, project evaluation was characterized by limited use of more sophisticated and quantitative selection techniques such as standard economic projections. (Clarke, p. 12) Discounted cash flow calculation is one of the methods used. (Freeman, p. 238)

Freeman hypothesized that rules of thumb and discounted cash flow methods are biased toward short-term payback and probably discourage the more radical type of innovation, which would find more favor either in a fairly sophisticated selection system or without any formal system. Mansfield's recent work seems to indicate a conservative bias in quantitative selection methods. (1977, p. 198) This is supported by a recent finding that R&D project selection methods of a formal, quantitative nature reduce the tendency to perform basic research. (Nason et al., p. 28)

Much innovation decisionmaking involves the evaluation of individual projects within the constraints of a total R&D budget. The total R&D budget may be determined as a percentage of sales or on the basis of a variety of other factors, including: historical patterns in the firm and its industry, the cash flow available, the amount needed to defend existing business; and the mood of the chief executive officer and his level of confidence in the chief of R&D. With resepct to individual project selection, most firms use some kind of portfolio approach—where high risk, high return projects are balanced with low risk, low return projects. Freeman points out:

> By thinking in terms of a portfolio rather than a project it is possible to select a blend of "safe" and "high risk" projects, so that the more long-term and radical advances are not ignored as they would tend to be if selection were based entirely on a scoring system or rate of return system. (p. 242)

Research by Mansfield on innovation decisionmaking in a large industrial laboratory indicated that innovation expenditures were in fact approached to a considerable extent as a portfolio of investments of varying degrees of risk and potential payoff.

Gold has recently suggested some additional notes of realism for the study of innovation decisionmaking. He pointed out that although profit is widely accepted as the primary incentive to innovate, this is actually an oversimplification. To understand firm decisionmaking for innovation, one must consider the context of the firm's internal decisionmaking environment and the broader business and public policy environments. Profit is one objective of the firm; other objectives may include survival, meeting governmental regulatory standards, meeting foreign competition, entering new markets, keeping old markets, and reducing reliance on increasingly expensive materials. The importance of any objective or need varies from time to time, and the analyst must be aware of the urgent problems facing a firm or industry at a given time. Innovation may not be a solution to the urgent problems facing the firm at that time.

Moreover, innovation is just one means of meeting a firm's objectives. In investment decisions, the net benefits from innovation are compared with those of alternative investments. When interest rates and inflation are high, the future benefits of innovation are heavily discounted and investments in ordinary stocks and bonds, acquisitions, or real estate may be preferred. The uncertainty of innovation means it is not known whether the innovation will indeed meet firm objectives, and non-innovation investments may be preferred because their benefits are easier to predict. That is, the firm may apply a high rate of discount for risk and uncertainty.

Innovation decisionmaking in the industrial firm appears to be much less "neat" than suggested by neoclassical economic theory. Rather than making precise calculations of costs and benefits, the firm appears to proceed incrementally and experimentally, trying to integrate its R&D program with perceived market opportunities and requirements. Although skill and good management are certainly related to success there is also an important element of chance. And it should be kept in mind that uncertainty gives rise to controversy and any calculations produced in the decisionmaking process may in reality be rationalizations for positions taken on the basis of a gut feeling. Keynes pointed out that if we waited for sure answers to all our questions, we would never risk undertaking an innovative project.

E. Effects on Innovative Activity

Because uncertainty tends to increase with the magnitude of technological change sought and the length of time necessary, much of industry's innovative activity is focused on relatively small advances of a short-term, low-risk nature. Uncertainty gives the firm an incentive not to undertake radical product innovations, but rather to focus on incremental, defensive, imitative, product differentiation and process innovation. And in fact, outside defense and space-related R&D, which is largely funded by the government, and possibly some segments of the civilian electronics and chemical industries, most corporate R&D is modest design improvement work, involving relatively short time frames.

Industrial R&D expenditures in Great Britain were found to be concentrated on the less uncertain types of projects. (Freeman, p. 243) Moreover, relatively few firms perform basic research, which is highly uncertain, and it accounted for less than 4 percent of industrially funded R&D in the United States in 1977. *Science Indicators 1976* reported that, of a sample of 277 major innovations introduced into the U.S. commercial market during the period 1953–1973, the largest percentage was rated as technological improvement (38 percent), followed by major technological shifts (28 percent), and radical breakthroughs (26 percent). (p. 111) (It should be noted that a study of major innovations would likely be biased toward major changes.) A study of a thousand new product announcements in Great Britain found that only 18 percent of them could be described as new products that involved technical change and were developed in the United Kingdom. Further, about half of those so classified were actually modifications of existing products of the company. (Freeman, p. 244) The impression that industry tends to invest in relatively safe, short-term innovation projects is also supported by the work of Hamberg, Mansfield, and others.

Nelson, Peck, and Kalachek described how risk and uncertainty factors lead to conservatism in the types of innovation projects undertaken:

> Expected R&D costs and risks are largely dependent on the magnitude of the advance sought. In many cases a relatively secure competitive position can be held with a product possessing only a relatively small performance or cost advantage over that of a competitor. Clearly there are strong incentives for doing enough R&D to maintain technical parity or a slight advantage over the competition: it may spell the difference between long-run survival and going out of business. However, the additional returns from a far-reaching R&D project may not be viewed by a cautious businessman as being worth the added uncertainties and costs, even though its success might place the firm far ahead of its competition. (p. 86)

There is some debate on whether innovation requires great risktaking on the part of industrial firms. Many claim that it is necessary for firms to be willing to undertake great risk for radical innovations to be forthcoming. They point to a decline in the risktaking propensity of American firms as a cause for the alleged decline in U.S. industrial innovation. Others argue that innovation does not proceed by taking great risks but is rather a process of recognizing a potential match between market need and technological opportunity and attempting to forge a match while reducing uncertainty and committing the smallest amount of capital possible. Possibly the source of the difference of opinion is that low risktaking is "normal" behavior, while high risktaking is regarded by some as desirable. (Klein, p. 188) However, even if a firm undertakes a risky project it may attempt to reduce the risk to the minimum possible.

If it is desired to induce industry to undertake high-risk innovation projects, it would be helpful to know the conditions under which industry is willing to do so. Freeman argued that the acceptance of a high level of uncertainty in innovation tends to be confined to the following categories:

> 1. A few small-firm innovators who are ready to make a big gamble, or who are impelled to do so by some threat to their existence.

2. Large-firm innovators who use careful project selection methods but who can afford to adopt a "portfolio" approach to their R&D, offsetting a few very uncertain investments against a large number of "mediocre" projects. The size of the very uncertain investments will not usually be such that failure would threaten the continued existence of the firm.

3. Large-firm innovators who are not closely controlled by any formal project selection system and who are able to use corporate resources with a good deal of freedom, and hence impose their subjective estimates or preferences upon the organization.

4. Large- and small-firm innovators who unwittingly accept a very high degree of uncertainty, through "animal spirits," because the enthusiasm of inventors, entrepreneurs, or "product" champions leads them on. In some cases (probably the majority) they may not bother to make any sophisticated calculations of the probable return on the investment. In others they may accept grossly overoptimistic, subjective estimates of the probable outcome.

5. Government-sponsored innovators who accept high risks because of urgent national needs (usually war, or threat of war) or a deliberate national science policy strategy, which creates an assured and profitable market in the event of success.

6. Government-sponsored innovators who accept grossly overoptimistic estimates of future returns for other reasons, where failure does not pose a serious threat to the decisionmakers. (pp. 237–238)

Thus, it seems that a high level of uncertainty is accepted only when the firm is forced to, can afford to, or does so unwittingly.

The incremental innovations on which industry focuses are sources of major economic benefits to the firm. This was documented in detailed fashion by Hollander in his study of the role of major and minor technological changes in creating productivity increases in Du Pont rayon plants. A study by Enos of petroleum refining reached similar conclusions.

In technological innovation, except perhaps for accidental discoveries, the risks tend to be commensurate with the potential payoffs. Major advances tend to entail high risk of failure but high payoff if successful. Minor advances tend to entail less risk, but also less payoff. Hollander found that in Du Pont rayon plants minor technical changes were relatively easy to accomplish, usually required small investment, and individually resulted in small cost reductions. Major technical changes were relatively difficult to accomplish, required significant investment, and usually resulted in significant benefits.

Whether a firm chooses a major advance over a minor advance may depend on whether its overall strategy is merely one of corporate survival or one of corporate preeminence. Minor innovation is a form of insurance against the firm's technology being made obsolete by changing technology and the efforts of competitors. This is the strategy chosen by most firms. Freeman discussed six alternative strategies: offensive, defensive, imitative, dependent, traditional, and opportunist.

Offensive.—An "offensive" innovation strategy is one designed to achieve technical and market leadership by being ahead of competitors in the introduction of new products. . . . [It involves heavy R&D spending.] Only a small minority of firms in any country are willing to follow an "offensive" innovation strategy, and even these are seldom able to do so consistently over a long period.

Defensive.—A "defensive" policy may be just as research-intensive as an "offensive" policy. The difference lies in the nature and timing of innovations. The "defensive" innovator does not wish to be the first in the world, but neither does he wish to be left behind by the tide of technical change.

Imitative.—The "imitative" firm does not aspire to "leap-frogging" or even to "keeping up with the game." It is content to follow way behind the leaders in established technologies, often a long way behind.

Dependent.—A "dependent" strategy involves the acceptance of an essentially satellite or subordinate role in relation to other stronger firms. The "dependent" firm does not attempt to initiate or even to imitate technical changes in its product, except as a result of specific requests from its customer or its parent.

Traditional.—The product supplied by the "traditional" firm changes little, if at all. . . . The "traditional" firm sees no reason to change its product because the market does not demand a change, and the competition does not compel it to do so.

Opportunist.—There is always the possibility that an entrepreneur will identify some new opportunity in the rapidly changing market, which may not require any in-house R&D, or complex design, but will enable him to prosper by finding an important "niche," and providing a product or service which consumers need, but nobody else has thought to provide. (pp. 258–277)

The fact that firms may choose alternative innovation strategies implies that one cannot explain firm behavior solely in terms of response to market forces. Technology is just as much a part of the firm's environment as the market, and the firm's responses to changes in technology cannot be reduced to reaction to market forces. Moreover, the choice of innovation strategy may represent, in large part, the personal views or values held by corporate officials.

F. Success and Failure in Innovation

The preceding discussion should make it clear that there are no guidelines that guarantee success in an innovative undertaking. A body of research has attempted to determine those factors that distinguish successful innovation projects from the failures; unfortunately this research literature has a number of shortcomings. For one thing, the criteria for success often differ. Technical success is different from commercial success. For another, most research has concentrated on successful projects without looking at failures, making it likely that many of the factors found to be associated with successful projects (such as top management support) may also be associated with failure. Nonetheless, it is possible to make some general statements about the kinds of factors that seem to distinguish successes from failures.

The best-known study of successful and unsuccessful innovations was Project SAPPHO, which compared pairs of similar innovations, one of which was a commercial success (had obtained a worthwhile market share and profit) and the other not. The innovations were selected on an international basis from the chemical process industries and the scientific instruments industry. The main finding was that no single factor can by itself explain the difference between success and failure. Analysis revealed five underlying areas of difference between successful and unsuccessful innovation:

(1) *Successful innovators were seen to have a much better understanding of user needs.* They may acquire this superiority in a variety of different ways. Some may collaborate intimately with potential customers to acquire the necessary knowledge of user requirements. Others may use thorough market studies. However acquired, this imaginative understanding is one of the hallmarks of success. Conversely failures often ignore users' requirements or even disregard their views.

(2) *Successful innovators pay much more attention to marketing.* Failures were sometimes characterized by neglect of market research, publicity and user education, and the failure to anticipate customer problems.

(3) *Successful innovators perform their development work more efficiently than failures, but not necessarily more quickly.* They eliminate technical defects

from the product or process before they launch it. They usually employ a larger development team on the project, and spend more money on it. This applies even where the successful firm is smaller.

(4) *Successful innovators make more effective use of outside technology and scientific advice*, even though they perform more of the work in house. They have better contacts with the scientific community not in general but in the *specific* area concerned.

(5) *The responsible individuals in the successful attempts are usually more senior and have greater authority than their counterparts who fail.* In the instrument industry they have more diverse experience, often including experience abroad. The greater power of the individual innovators in the successful attempts facilitates the concentration of effort on the scale which is needed as well as the integration of R&D and marketing. (Science Policy Research Units, p. 5)

The importance of market awareness and marketing effort to innovation success has been commented upon by many researchers. (See for example, Schon.) Pavitt and Walker noted that most innovation studies have found successful innovation to be associated with attention to, or accurate estimation of, potential markets, but the studies are inconsistent on whether the use of formal project selection procedures and successful prediction of project outcomes are associated with successful innovation. (p. 26) Prediction of size of potential market is very difficult, as pointed out earlier.

Successful innovation seems to depend on how well the firm combines technical with market knowledge, Mansfield has recently noted:

Judging from the results of past research, successful innovation depends in an important way on R & D being integrated with marketing. The R & D personnel must be able and willing to respond to the marketing personnel's needs, and marketing personnel should be involved in R&D project selection. In contrast, the R & D personnel in some firms have been quite remote at times from the marketing personnel, and have marched to the beat of quite a different drummer, the result being that the R&D output has been more poorly mated with market conditions that would otherwise have been the case. (1977, p. 33)

Marketing seems to be especially important for product innovations. For process innovations, the relevant users may be within the firm, i.e., the production department.

Von Hippel (1976) has recently done research showing the need for the innovation supplier and user to work closely together. In some industries, such as scientific instruments, the users of the innovation are often the source of the idea, which is then developed and manufactured by the supplying firm. Exploratory work by Souder describing the mechanisms used by firms to manage the interaction between R&D and marketing functions has shown that there does not appear to be a single best mechanism, but rather that the most effective mechanism depends on the nature of the technology, the nature of the markets, and the existing climate between R&D and marketing. (p. 9)

IV. Industrial Organization and Technological Innovation

Technological innovation is a major component of industrial competition. The introduction of a better-performing product by a competitor may have drastic effects on the sales of other firms. For instance, upon the introduction of American Cyanamid's Achromycin tetracycline in 1953, sales of Aureomycin chlortetracycline, which had been increasing since late 1948, dropped by nearly 40 percent during the first full year. (Mansfield, 1968 A, p. 7) Schumpeter, writing in 1942, stressed the importance of technological competition over ordinary competition which operates within fixed conditions of technology. Technological competition, he said:

> . . . strikes not at the margins of the profits, and the outputs of existing firms, but at their very lives. This kind of competition is as much more effective than the other as a bombardment is in comparison with forcing a door, and so much more important that it becomes a matter of comparative indifference whether competition in the ordinary sense functions more or less promptly . . . (Quoted in Freeman, p. 159)

Much research in this area has centered around the so-called Schumpeterian hypothesis which, as restated by Kamien and Schwartz, is that "an industry composed of large firms with a degree of monopoly power in pricing would, through the market system, allocate resources more efficiently in the long run than any alternative institutional arrangement." (p. 24) There have been some differences in the interpretation of the hypothesis. The Kamien and Schwartz interpretation seems to indicate that market structure (oligopoly) leads to increased innovation. Nelson and Winter, on the other hand, interpreted Schumpeter's argument to concern transient monopoly as a consequence of, and lure for, innovation, not monopoly as a stimulus for innovation. (p. 70)

A significant innovation can give one firm a major advantage over others. Thus, as in aviation and computers, where firms can grow rapidly and there are few limits on firm size, and where imitation is difficult, monopoly structures may develop out of the innovation process itself.

Kamien and Schwartz pointed out:

> Large size and monopoly power were regarded as complementary attributes [in the Schumpeterian hypothesis], the former influencing the breadth of the market for the innovation and the latter its duration. Subsidiary hypotheses included the suppositions that large diversified firms would undertake more research than small single product firms and that large monopolistic firms would attract the best innovative talent. These hypotheses, supported with anecdotes by their originators, were vague regarding the definitions of firm size, monopoly power, and inventive activity. This lack of specificity has led to a wide range of interpretations of the hypotheses and disagreement about the relevant empirical tests. (p. 24)

Subsequent research has focused on firm size, industrial concentration, market entry, and diversification. The findings in regard to the relationships between the above variables and innovation have not been conclusive, leading some researchers to believe that the relationships have not yet been properly conceptualized.

A. Firm Size and Innovation

The research on the relationship between firm size and technological innovation has typically measured innovation in one of three ways: R&D expenditures; patents; and counts of major innovations. Research and development expenditures are an unsatisfactory measure of innovation because they measure inputs, rather than the firm's ability to convert R&D inputs into successful innovations. Moreover, R&D expenditures may represent a minor portion of total innovation costs, depending on the industry. On the other hand, data on industrial R&D expenditures are readily available.

Patents also have a number of drawbacks as measures of innovation. They indicate the existence of an invention, which may not be commercialized, and not all inventions are patentable. Moreover, most patent studies do not weigh patents to account for the differences in degree of technological advance or economic significance. There is some evidence that small firms rely more heavily on patent protection than large firms, which would bias this measure in favor of small firms. On the other hand, small firms may not be able to afford to patent as much as large firms.

Studies based on counts of innovations generally depend on a relatively small and less reliable data base than the other studies. Data on innovations are not collected in a regular and consistent manner. Thus, studies based on number of innovations, while inherently more satisfying, are likely to be based on unrepresentative data and hence are less capable of generalization.

Firm size has typically been measured by size of employment, sales, or R&D program. There has not been a consistent definition of "small," "medium," and "large" firms.

This section of the paper will review research on the relationship between firm size and R&D, then firm size and inventions, and finally firm size and number of innovations. But first it would be helpful to review the arguments in favor of, and against, a predominant role for large firms in technological innovation. Mansfield summarized some of the reasons given for a predominant large firm role:

> . . . a large firm can finance R and D more easily, it can afford bigger projects, the results of R and D are more likely to be useful because of its [the firm's] greater diversity, it can wait longer for the pay-off, and it can capture a larger portion of the social gains from its research because it has a larger share of the market. (1968 A, p. 93)

R&D often involves economies of scale that only large firms can efficiently exploit and large firms have the option of acquiring new technological expertise by buying a small firm with existing capability in an unfamiliar area. (Staples, et. al., p. 71) Some argue that large firms have a greater willingness to take chances.

On the other hand, there are arguments against a predominant innovation role for large firms. These have been summarized by Staples et al.:

> Those who deny that the large firm is primarily responsible for technological advance point to its organizational characteristics and note that they present serious barriers to the effective employment of the large firm's resources to R&D. They maintain that the long chain of command inherent in a large firm will produce a natural bias against imaginative R&D projects and will reduce the firm's risk-taking propensities. [footnote omitted] In addition, corporate policy directives which are used to control the routine aspects of other activities of the large firm are not particularly suited to R&D. Therefore the cost of maintaining information flows and coordinating and controlling R&D activities will be great in the large firm. [footnote omitted] It is finally argued that because R&D is overstructured in large firms, creativity will be reduced or driven out. [footnote omitted] Thus small firms, unhampered by organizational restrictions and many times under the direction of a creative refugee from the large lab, are more likely to be the source of more revolutionary innovations, while large firms will be geared to more incremental types of innovations. [footnote omitted] (p. 71)

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1. FIRM SIZE AND R&D

Research and development activities are heavily concentrated in large firms. Most small firms perform no formal, organized R&D at all. In the United States, France, Britain and most other countries, the proportion of small firms (defined as fewer than 200 employees) performing R&D is less than 5 percent. (Freeman) The strength of relationships between R&D expenditures and firm size seems to depend on whether all firms are included or just those firms that perform R&D, becoming stronger when all firms are included. Among those firms that do perform R&D, there is a significant correlation between firm size (in terms of employment) and R&D expenditures in most industries.

The degree of concentration by size of R&D program is even more marked than by size of firm (classified by total employment). In 1975 the R&D expenditures in the 40 largest U.S. industrial R&D programs were approximately equivalent to those of the 116 largest firms, each accounting for about 70 percent of the total. (National Science Foundation, 1977 (C), pp. 6, 41) Federally funded industrial R&D is even more concentrated. Despite the high concentration of R&D there are some large firms that perform relatively little R&D (see "R&D Spending at 683 Companies") and some small firms which perform a good deal.

With respect to company-funded R&D expenditures relative to sales (commonly called R&D intensity), in most industries the correlation between R&D intensity and firm size is relatively weak and in some cases is apparently inverse. Research by Mansfield, Scherer, Freeman, Markham, and others seems to indicate that, except for the chemical industry, the largest firms in an industry do not spend more on R&D, relatively to sales, than do somewhat smaller firms that perform R&D. There is some evidence that R&D intensity increases with firm size up to some intermediate level, which varies from industry to industry, and then diminishes with size above that level. For example, Mansfield found that in the petroleum, drug, and glass industries, the largest firms spent significantly less on R&D relative to their sales, than smaller firms. When total R&D funding is considered, Federal contracts seem to account for the greater R&D intensity of large firms. (Freeman, p. 203)

Kamien and Schwartz summarized the findings of a literature review with respect to the relation between firm size and the efficiency of R&D performance:

> Studies have consistently found actual R&D to be done more efficiently in small or medium size firms than in large firms; it has been estimated that any given project would cost three to ten times as much to develop by a large firm as by a small one. Beyond a certain not very large size, increasing firm size tends to be accompanied by a reduction in patented output per R&D dollar, a reduction in the portion of patented inventions that are commercially employed, and decline in the number of significant inventions per R&D dollar. (p. 23)

Science Indicators 1976 found, on the basis of a sample of major innovations introduced to the market between 1953 and 1973, that small firms (up to 1,000 employees) produced about four times as many innovations per R&D dollar as medium-sized firms (1,000 to 10,000 employees) and about 24 times as many as large firms (over 10,000 employees). (p. 82). These data are weakened by methodological problems, however.

Freeman postulated some reasons that small and medium-size firms may undertake R&D as a way of explaining weak correlations and inter-industry variation. He hypothesized that the few small firms and many of the medium sized firms that perform R&D tend to fall into three categories:

1. Firms which have just begun to develop or exploit a new invention. In this case sales could be relatively low in relation to R&D and a very high research-intensity could be expected. This might tend to fall in the event of successful commercial exploitation of the innovation and growth of the firm and its sales.
2. Highly specialized firms which have a particular expertise, sustained by an intensive research programme in a very narrow field. Here too, research-intensity might often be high.
3. Firms struggling to survive in industries in which new product competition makes R&D increasingly necessary. A very varied management response might be expected in these circumstances, with some firms trying to scrape by with a sub-threshold R&D effort, others relying mainly on cooperative research, and still others taking high risks with an ambitious programme. (pp. 202–203)

Thus, although most R&D expenditures are concentrated in large firms, company-funded R&D expenditures relative to sales within industries are not strongly correlated with firm size. Moreover, small firms that perform R&D do so more efficiently than large firms, in terms of innovations per R&D dollar.

2. FIRM SIZE AND INVENTION

Another branch of this research involves the study of the roles of large and small firms in invention. (Invention, it will be recalled, is an idea, sketch, or model for a new or improved product, process, device, or system. Not until an invention is reduced to practice and commercialized is it an innovation.) Jewkes et al. in a detailed study of the sources of inventions, attempted to show that most major inventions in the 20th century have been made outside the R&D programs of large firms. Jewkes' analysis has been criticized on the grounds that some important corporate inventions were omitted and that the contribution of large firms to his list of inventions was weak before 1930 but dominant thereafter. (Freeman, p. 208) Nonetheless, Jewkes and his colleagues made a strong case for the view that small firms, private inventors, and universities have made a disproportionately large contribution to the more radical type of 20th century inventions.

Freeman's research confirmed the importance of universities, private inventors, and small firms in invention. The relative performance of large firms is apparently better with respect to innovations than with respect to inventions, however, and their role in development work (which is usually far more expensive) is much more important. (p. 109) Small firms may have some comparative advantage in the earlier stages of inventive work and the less expensive—but more radical—innovations, while large firms have an advantage in the later stages and in improvement and scaling up of early breakthroughs. (p. 209)

Jewkes et al. maintained that the private inventor still plays an important role in invention. Although corporations are now accounting for a larger part of useful patents, they said, their part is probably exaggerated by patent statistics. Other researchers, however, have said that the role of the large firm tends to be underrepresented by patent statistics. It is well established that many major inventions have originated in the laboratories of independent inventors. They often have to turn their idea over to a larger organization, however, that has the resources to develop and commercialize it. The prominence of independent inventors today appears to vary by industry.

3. FIRM SIZE AND NUMBER OF INNOVATIONS

Other research has studied the relationship of firm size to the number of innovations produced. Large firms account for most innovations as would be expected based on their large resources. Small firms account for a small proportion of total innovations, but they contribute more than proportionately to their share of employment or output. The precise proportions would vary with definition of small and large. Freeman's study of small (up to 199 employees), medium (200–999 employees) and large (more than 1,000 employees) firms in the United Kingdom concluded that small firms contributed about 10 percent and large firms about 80 percent. (p. 212)

Mansfield found that the four largest firms accounted for a disproportionate share of major innovations relative to their market share in the petroleum refining, bituminous coal, and railroading industries, but they accounted for fewer in the iron and steel industry. He hypothesized that the largest firms in an industry would do proportionately more innovating under the following conditions:

> . . . (1) the innovation requires a large investment relative to the size of the potential users of the innovation, (2) the minimum size of firm to which the innovation would apply is large relative to the average size of firm in the industry, and (3) the average size of the largest four firms in the relevant industry is much greater than the average size of all firms which are potential users of the innovation. (1968 A, p. 110)

He found that this theory accounted for much of the variation.

More recent research by Mansfield et al. on the chemical industry found no evidence that the biggest chemical firms did any more innovating, relative to their size, than somewhat smaller firms, in the case of *process* innovations. But the biggest firm, Du Pont, was responsible for the most *product* innovations relative to its size. Mansfield and others concluded:

> . . . Du Pont seems to be the only case encountered thus far where the biggest firm in an industry has done the most innovating (relative to its size)—and even in the case of Du Pont, this is true only for products, not processes. (1977, p. 204)

Mansfield hypothesized that one reason why the chemical industry is the only case yet found where the largest firm does the most innovating relative to its size is that innovations, particularly product innovations, tend to be very expensive relative to the distribution of firm sizes in that industry.

Kamien and Schwartz, on the basis of a literature survey, found little support for the hypothesis that intensity of innovational activity increases with firm size. They found intensity to increase with firm size until it was greatest for intermediate size firms. For larger firms, innovation intensity appeared to be constant or declining with firm size. (p. 24)

The evidence from project SAPPHO suggested that between competitive attempts to innovate, size does not affect who succeeds very much. But since some innovations are too costly for small firms to attempt, competition on those innovations will be limited to large firms.

Freeman's research in Great Britain indicated that small firms tended to make significant innovations in industries that do not require large-scale capital investment or large-scale R&D, such as machinery and instruments. In industries of high capital intensity or large-scale R&D requirements, large firms tended to dominate and small firms tended not to contribute innovations. Small firms also contributed significantly to innovations in traditional industries such as textiles, leather, and furniture.

4. SUMMARY

Research and development, invention, and innovation are not the sole preserve of either large or small firms; they are carried on in firms of all sizes. Although it is true that most small firms perform no R&D or innovation, evidence suggests that small firms that perform these activities do so more efficiently than large firms. Small firms and independent inventors have been the sources of some of the most important inventions of this century. These inventions, however, have often required the resources of large corporations to commercialize them.

Large and small firms have different advantages with respect to the performance of innovation. The advantage of large firms seems to be their resource base in terms of finances and R&D facilities. The advantage of small firms seems to be their flexibility and ease of internal communication. Small firms make significant contributions in the less costly phases of innovation and in industries which are not especially capital intensive or where innovation is not very expensive. Increasing complexity of technology, cost of development, and rate of change make it more difficult for small firms to innovate and compete.

The roles of small and large firms vary by industry. The largest firms seem to do a disproportionate amount of innovating in those industries in which innovation is extremely costly relative to the size of the firms.

There is a tendency in most industries for larger firms to be more R&D intensive than smaller firms. This is largely due to the majority of small firms which perform no R&D at all, and the large concentration of federally funded R&D in large firms. If these two influences are removed, the correlation between firm size and R&D intensity is weak.

B. Industrial Concentration and Innovation

There has been much concern about the relationship between innovation and the conditions of competition in industry. The usual measure of competition is a concentration ratio, the portion of industry sales attributable to the four (or eight) largest firms in an industry.

There are theoretical arguments for and against the hypothesis that a high degree of concentration or monopoly power is conducive to innovation in an industry. (Staples et al., p. 72) On the one hand, it is argued that only firms with a high degree of monopoly power have the financial resources necessary to undertake innovation. It is said that an industry with many firms able to imitate innovations rapidly reduces the prospective rewards to potential innovators, and slows the rate of innovation. It is also asserted that highly concentrated industries exhibit less price competition and the resulting search for product differentiation will stimulate R&D, although perhaps of a trivial sort. On the other hand, it is argued that monopolistic market power reduces competitive pressure, and thus reduces the *pressure* to innovate. It is also maintained that the more rivals there are in an industry, the larger the share of the market there is to be gained by innovating first. The case is also made that, although they innovate slowly, dominant firms are quick to imitate the innovations of rivals.

The empirical findings provide no consensus on the theoretical arguments. According to Kamien and Schwartz:

> High industry concentration has been alternatively found to be harmful, neutral, and helpful to innovational activity. In most instances, it has been difficult to discern a strong statistical relationship between the variables employed. There is a little evidence that an intermediate degree of rivalry may be most conducive to innovation. (p. 24)

Pavitt and Walker argued that:

> . . . the ideal degree of industrial concentration will vary from sector to sector, indeed from product to product; it will depend on both the size of the potential market and the costs of developing the innovation, and both these will vary widely from case to case. (p. 37)

Concentration tends to be higher in R&D-intensive industries. Some people argue that this high degree of concentration is one of the reasons research-intensive industries are innovative. Others, however, argue that it is because research-intensive industries are innovative that they have become concentrated and not vice-versa. Successful innovation in these industries results in the rapid growth of the innovating firm. Hence, a high degree of concentration develops among the consistently successful innovating firms. (Pavitt and Walker, p. 36) The fact that innovating firms are frequently unsuccessful may prevent the degree of concentration from becoming even higher.

In summary, no general or systematic relation has been found between the degree of industrial concentration and industrial innovation. Neither competition nor monopoly can be singled out as necessarily encouraging to innovation. Innovation seems to be associated with a balance of competitive risk and monopoly-power safety, the nature of the balance required depending on the circumstances of the industry. The causal connection between concentration and innovation may run both ways. If that is the case, the relative strength of the two directions may be the question.

C. Market Entry and Innovation

The entry of new firms into a market has been an important stimulus to competition and innovation. Examples of entrants introducing innovations that established firms failed to develop or attempted to suppress are many: the incandescent lamp, the electric typewriter, radio, the transistor radio, and cable television. (Gilpin, p. 42) In oligopolistic industries where patterns of firm conduct are well established, the tendency may be not to innovate until an "outsider" firm seeks entry.

There are generally barriers of varying degrees of severity to the entry of new firms into an industry. These may take the form of capital requirements, regulatory exclusions or standards, or minimum R&D level requirements. MacLaurin showed that in some cases the dominant firms in an industry have used their power to try to exclude new entrants, sometimes in cooperation with regulatory agencies.

Freeman has described the R&D barrier to entry as it exists in the electronic capital goods industry. In that industry:

> . . . [e]ntry is restricted by R&D capacity and by the need to provide marketing and technical service facilities. Each firm which wishes to stay in the business must be capable, if not of making a major innovation itself, at least of imitating those made by its more advanced competitors within a short time. To do this it must have a certain R&D capacity, even if it also makes use of licensing and knowhow agreements. . . .
>
> In this situation every firm must have a minimum level of R&D work in progress, sufficient to keep abreast of the technical changes in components, to introduce a flow of improvements and to launch completely new models when forced to do so by the competition. This minimum level of "defensive" research and development may be termed the "threshold." It is an *absolute* level of resources, not a *ratio* of sales.
>
> Below this "threshold" level of R&D expenditure it will normally be impossible to develop new products with lead times short enough to survive. The "threshold" is low for some types of electronic instruments, and many small firms prosper in this part of the industry; indeed, because of their flexibility and speed of reaction, they may have some competitive advantage over larger firms. It is also fairly low for "minicomputers" but for more complex products, such as [main frame] computers, communication satellites or electronic telephone exchanges, the threshold is very high. (pp. 152–157)

With respect to the effect of market entry conditions on industrial innovation, Kamien and Schwartz concluded that industrial R&D effort may be strongest in industries with an intermediate technical entry barrier, where rapid imitation is impeded, but entry has not been effectively foreclosed. (p. 24)

D. Diversification and Innovation

Another element of industrial organization that has been studied with regard to innovation is diversification. Staples et al. summarized this research:

> The effect of diversification is unclear, in spite of its increasing important [sic] to business. It has been postulated that increased diversification of a firm is conducive to innovation, since there is a greater likelihood that research will produce something of value to one of the firm's interests. The evidence is again inconclusive, resulting in positive, negative or no correlation, though there is some evidence that high research intensity is associated with diversification into similar industries. Diversification may be a factor in the inconsistencies exhibited in most of the empirical studies in this area since "R&D expenditures in terms of product areas, rather than industries, are more indicative of the actual composition and focus of national effort in industrial R&D." [footnotes omitted] (p. 74)

E. Spin-Off Firms

Spinoff firms make significant contributions to technological change in some industries. Freeman discussed the importance of spinoff firms in the electronic components industry:

> Diffusion of technical know-how does not simply depend on ability to pay. It owes a great deal to personal contacts and discussion, or to the movement of people—and here American firms enjoyed a major advantage. The Research Director of Texas Instruments came from Bell and so did other key personnel in the American semiconductor industry. . . . Texas Instruments and other firms, such as Fairchild and Motorola, have since made very important contributions to the development of semiconducting devices, especially to manufacturing techniques and to the development of integrated and monolithic circuits. . . . Golding has documented in detail the great importance of the movement of key R&D personnel in the development of the American semiconductor industry, initially from Bell and later from other firms, to establish new groups and enterprises. (p. 146)

The formation of spinoff firms to exploit a new technical idea was prominent in the 1960's and resulted in the concentration of small, high-technology companies around Boston and San Francisco. Typically, a technical entrepreneur in a large firm or university saw an opportunity to commercialize an idea and became dissatisfied by the parent institution's lack of support. Such a person often formed his own company to exploit the idea. One of the advantages of such firms was the person-embodied technical knowledge transferred from the parent institution.

F. Industrial Life Cycle

The review of relationships between elements of market structure and industrial innovation has shown it to be a very complex area. There are important variations between R&D, invention, and innovation; among industries; and among different elements of market structure. Many of the correlations are weak. Theories of industrial life cycles and the cyclic nature of technological innovation may help explain some of the variation.

The concept of the life cycle of an industry or an industrial technology is not new; Kuznets and Jerome described them in the 1930's. It has been widely observed that young industries, such as the electronics industry, are frequently based on a new technology and exhibit a high rate of innovation in their early years. In mature industries, on the other hand, the rate of technological change has slowed and most of the innovation that is undertaken by firms in the industry consists of incremental improvements on existing technology. Radical innovation often comes from the entry of new firms into the industry or through the innovations of other industries, such as the chemical industry in the case of textiles. As an industry matures, the economic advantage over sustained periods lies not in the rapid development of radically new products or processes, but rather in minor improvement innovations. Eventually, an entirely new product may result in the birth of a new industry and the death of the old one. For example, the automobile was such an innovation, replacing or drastically changing previous industries centered around horse transportation.

Rosenberg described a cycle that occurs in the life of individual innovations. He said:

> Major improvements in productivity often continue to come long after the initial innovation as the product goes through innumerable minor modifications and alterations in design to meet the needs of specialized users. Widely used products like the electric motor, the machine tool or the transistor experience a proliferation of changes, as they are adapted to the varying range of needs of ultimate users. . . . Such modifications are achieved by unspectacular design and engineering activities, but they constitute the substance of much productivity improvement and increased consumer well-being in industrial economies.
>
> Much of the technological change which goes on in an advanced industrial economy is, therefore, if not invisible, at least of a low visibility sort. It includes a flow of rather prosaic improvements in such areas as materials handling, the redesign of productive equipment and final products for greater convenience, and measures which reduce maintenance and repair costs, as in modular machinery design. . . . The cumulative impact of these individually small changes has . . . been very substantial. . . . (1976. p 25)

The significance of the small, cumulative improvements as they contribute to technological change and productivity was underlined in studies by Hollander of Du Pont rayon plants and by Enos of petroleum refining. These studies found that the cumulative impact of the minor improvements was equal to or greater than the effect of the parent, major changes. However, the minor improvements eventually exhausted themselves, and another major change was necessary for further technological change and productivity improvements.

Similar models have been developed by Mueller and Tilton and by Abernathy and Utterback. These models argue that the relationship between market structure and industrial innovation depends on the stage of technological maturity in which a particular industry finds itself. They postulate that an industry passes through different stages as the technology that created it evolves. Both models are concisely summarized by Staples et al.

In the Mueller and Tilton model, four stages are denoted: Innovation; imitation; technological competition; and standardization. The innovation stage begins with the invention of a new product or process and ends with its successful introduction into the market. Small firms are not at a disadvantage in this stage and have been responsible for the invention and development of important innovations in many cases. Large firms have some disadvantage due to communication and incentive problems. This stage shows the most technical and marketing uncertainty. Economies of scale do not yet exist in R&D, production, or marketing; thus neither vast amounts of resources nor market power is necessary.

In the imitation stage, technical and marketing uncertainties are considerably lessened and other firms can learn from the innovating firm. Rapid entry into the industry can be expected. Firms will engage in R&D to expand knowledge and improve the original innovation. The basic science and technology are crudely understood during this stage so a large investment in R&D is not necessary to be competitive. Both large and small firms are able to enter and succeed.

The industry passes into the technological competition stage as the science and technology becomes better understood. Research becomes more specialized and sophisticated. Large laboratories have the greatest advantage here, especially if economies of scale in R&D are a factor. Some small firms will have become large firms by now. Other small firms may succeed if they corner a specialized area of the technology and have patent protection. New small firms will have difficulty entering, however, and entry will be generally slow. The market, which has been growing to this point, begins to slow in growth.

The standardization stage is reached as the scientific knowledge becomes well-known, production techniques become standardized, and technological progress slows. Competition shifts from technology to price and the primary barriers to entry are the capital requirements for production technology and marketing organization. Entry is slow.

The Abernathy and Utterback model focuses on "process segments" within the firm. According to their model, process development within a process segment evolves through three stages: Uncoordinated, segmental, and systemic. Correspondingly, product development passes through three stages: Performance maximizing, sales maximizing, and cost minimizing.

In the uncoordinated stage, product innovations are likely to be major. They emphasize quality and performance, rather than cost. User needs are not yet well understood and users are likely to be active in providing the direction for innovation. Thus, product design and characteristics are constantly changing. Because the product is still evolving, production processes are adaptable, but inefficient. They tend to be small scale and characterized by manual operations and general-purpose equipment and materials. At this stage, the market is still small.

In the segmental stage, user needs become more clearly known, some products become more standard, and the market expands. These conditions encourage the automation of some phases of the production process. Other phases, however, remain manual, so the process assumes a segmented character. Firms pursue a strategy of product differentiation in an attempt to maximize sales, but the major innovations in this stage are process innovations. Both product and process innovation tend to be technology-stimulated, as opposed to market stimulated.

The last stage is the systemic stage, in which the product is standardized, user needs are clearly defined and made known to the firm, and the primary emphasis is on cost. Production processes are large scale, specialized, and fully integrated. Thus, the cost of changing the process to accommodate a major change in the product is prohibitively high. Consequently, innovations in either product or production process are likely to be limited to incremental changes. Revolutionary changes are likely to originate outside the process segment and enter by "invasion." Product strategy is cost minimizing.

These models show how patterns in the level and nature of innovative activity change as an industry evolves. They also show differences between stages of industrial maturation in terms of the type of competition (technology-based or price-based), between the level of resource requirements and the ability of small firms to succeed, between different motivations for the firm, and between severity and nature of barriers to entry. They have implications for the kinds of strategies firms will pursue, the kinds of stimulus that will motivate them to innovate, and the kinds of innovations that will be forthcoming.

V. Diffusion of Industrial Innovations

A. Introduction

Diffusion is the spread of an innovation once it has been introduced. It is a very important part of the innovation process because it is only through the spread of innovations that their economic and social impacts are made. Innovations may diffuse among users in the public sector, as well as the private sector; some of the issues involved in public-sector diffusion are discussed by Roessner (1976). Innovations also diffuse among consumers; examples include the diffusion of color television, fluoride toothpastes, and microwave cookers. This chapter, however, focuses on diffusion of innovations among industrial firms.

At any given time the firms in an industry are using a mixture of different production processes of varying levels of efficiency and are producing products of varying levels of performance or quality. Through the process of diffusion, this mixture is changed in the direction of more modern and efficient production processes and new and improved products. Thus, diffusion is important to industrial productivity growth and international competitiveness. Since a process innovation usually results in productivity improvement in the firm using it, the rate of the spread of that innovation will determine how rapidly overall industrial productivity increases in response to the new process. Moreover, the spread of an innovation affects not only the industry using that innovation but also its customer firms. For instance, a process innovation may result in a product with slightly different properties that will then create opportunities for innovation in the industries that use that product. In the case of product innovations, the new products will frequently increase the productivity of the using industries.

Diffusion may take a long time. Based on a study of 12 innovations, Mansfield concluded that 20 years or more was required in many cases before all the major firms in an industry had begun using an innovation. (1968 A, p. 133) The small firms were in many cases unable to use the innovation at all. However, there was a great deal of variation in the diffusion rates; sometimes it took decades for an innovation to be widely adopted while in other cases diffusion occurred very quickly. The number of years elapsing before half the firms had introduced an innovation varied from 0.9 to 15. Mansfield has provided evidence, based on a limited sample, that rates of diffusion may be increasing slightly. (1968 A, p. 131; 1977, p. 114)

The spread of innovations may occur through three mechanisms; the growth of the original innovator; the adoption of the innovation for the same purpose by other firms; and the application of the innovation for other purposes. The second mechanism has been studied the most, although it has been argued that the third mechanism accounts for the most dramatic spread of the innovation.

The diffusion of industrial innovations has not been studied as much as R&D and the generation of industrial innovations. Most diffusion studies have been of process, as opposed to product, innovations. Early studies of the diffusion of industrial innovations were based on the so-called "classical" model of diffusion developed by sociologists in studies of diffusion of agricultural and other innovations among individual adopters. (Rogers and Shoemaker) These studies stressed measures of the rate of diffusion and the characteristics of early and late adopters.

B. The "S" Curve

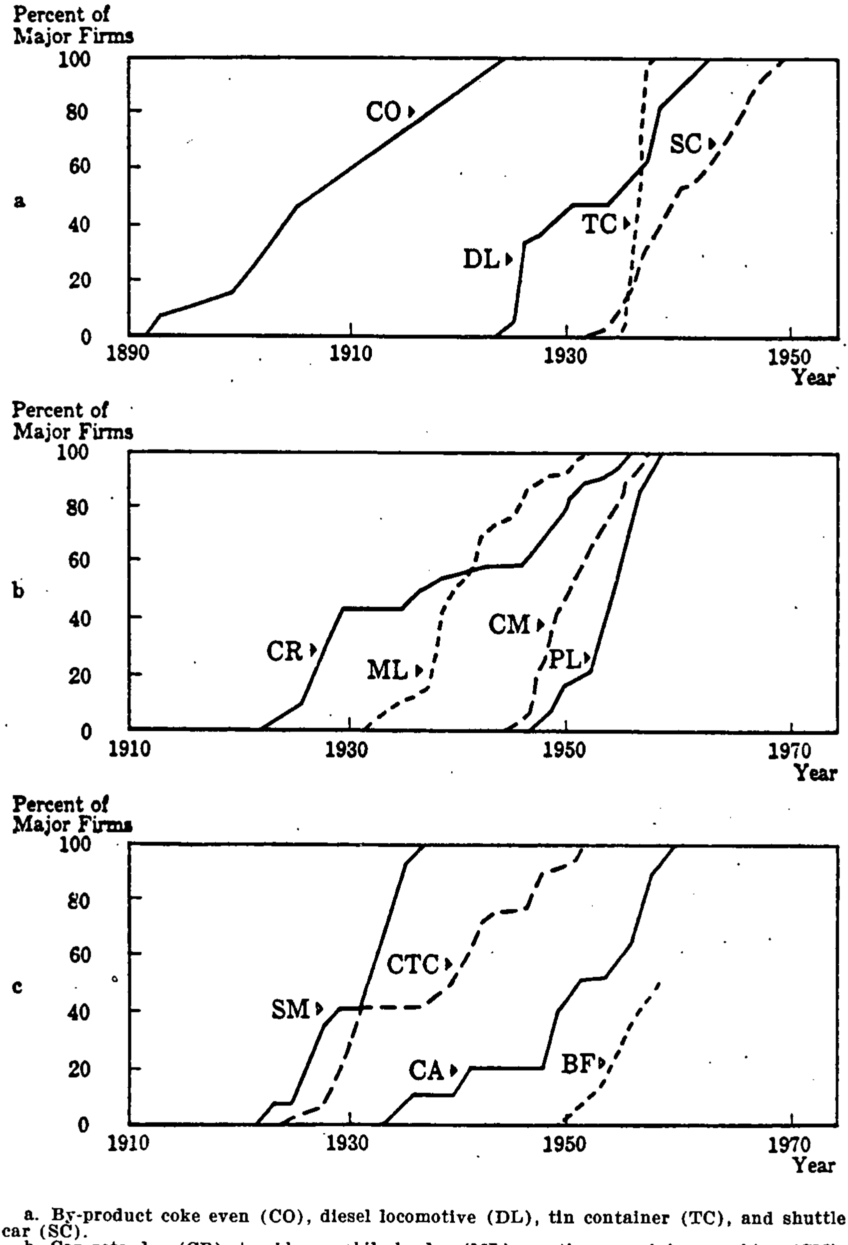
Early studies provided evidence that the diffusion of many innovations exhibits an S-shaped pattern. In the graphs in figure 3, the bottom axis represents time and the vertical axis represents percentage of potential adopters having adopted. In general the steeper the "S", the more rapidly the innovation diffused among potential users. The level of diffusion may be measured in a number of ways. Mansfield measured it in terms of the percentage of firms in an industry that adopted the innovation. This measure has been criticized for its failure to take account of the economic impacts (that is, 100 small firms adopting an innovation may not have the same impact as 4 giant firms adopting.) Some studies have therefore used the fraction of industry's output which utilizes the innovation as the measure of diffusion. (Lakhani)

The "S" shape of the diffusion curve is often explained as a result of learning processes: a few users try the innovation, others observe and presumably become convinced of its advantages enough to adopt it themselves, causing a rush of adopters. As adoption approaches 100 percent (or, stated differently, the market approaches saturation), there are a few stragglers or "laggards" that adopt much later than the rest of the industry. A problem with this type of analysis is the labeling of firms as "leaders," "followers," and "laggards." Such labeling may be inappropriate since a firm may be early to adopt one innovation and late to adopt another. Moreover, firms may have economic reasons for not adopting quickly, or at all, as will be discussed later in this section.

Recently, diffusion researchers have questioned the "S" curve. There is some evidence that S-shaped curves are not accurate descriptions of reality; the relationships may actually be linear. (Gold, p. 6) Another question that has been raised is how the universe of potential adopters can be identified. For a hybrid seed corn the answer might be all corn farmers; but if it is a seed developed for certain soil conditions then it would only be corn farmers with those soil conditions. Sometimes an innovation does not meet the needs of intended users and therefore never diffuses to 100 percent of intended users. This underscores the difficulty of forecasting the size of market and rate of growth of sales for new products.

On the other hand, uses are often found for innovations that were not imagined when it was first introduced. For instance, the uses of semiconductors were first intended to be primarily in the national defense area, but subsequent applications were found in consumer products, opening up whole new markets. Moreover, most innovations do not remain static once introduced to the market. The suppliers continually strive to improve them and to modify or adapt them for new applications. Continual modification creates a problem of knowing when the same innovation is being used. The number of potential users may increase continually, often as a result of the innovator's marketing efforts. Thus, the diffusion of an innovation may not only represent

FIGURE 3.—Growth in the Percentage of Major Firms that Introduced 12 Innovations, Bituminous Coal, Iron and Steel, Brewing, and Railroad Industries, 1890–1958.



a. By-product coke even (CO), diesel locomotive (DL), tin container (TC), and shuttle car (SC).
b. Car retarder (CR), trackless mobile loader (ML), continuous-mining machine (CM), and pallet-loading machine (PL).
c. Continuous wide strip mill (SM), centralized traffic control (CTC), continuous annealing (CA), and high-speed bottle filler (BF).

Source: E. Mansfield, 1968B, Chapter VII.

increasing saturation of the originally perceived market, but also the increasing range of applications. At any rate, it is difficult to interpret the meaning of the S-shaped curves when the innovation and the potential population of users change.

C. Adoption of Innovations

Industrial innovations spread through the decisions of user firms to adopt the innovation, decisions which are guided by the firms' perception of their own interests. Adoption often entails purchasing or building new plant and equipment and scrapping the old. Thus the decision to adopt is affected not only by the perceived benefits of the innovation but also by the availability of financial capital and other factors that affect the rate of investment generally. Adopting an innovation involves considerable risk or uncertainty. For each new user, a technology is an innovation, regardless of its age, in terms of the risk and uncertainty it poses to the firm. Thus, the earlier discussion of innovation as a process of uncertainty-reduction applies to decisions to adopt an innovation, as well.

It is widely agreed that the firm's primary consideration in deciding whether to adopt an innovation is its relative advantage over the status quo, discounted for uncertainty about adverse outcomes. According to Gold, however, this is overly simplistic and does not explain how the firm makes its decision. Gold said:

> . . . the guiding basis for such decisions is a comparison of the estimated effects on the performance of the firm over an extended period of adopting any particular innovation as over against allocating available resources to other means of dealing with its problems and opportunities. Understanding such decisions accordingly requires some grasp of the larger decisionmaking framework of firms within which decisions about innovations represent only an occasional intermediate stage rather than a continuous independent process. (pp. 10–11)

Firms or plants differ in respect to their objectives, costs, materials, resources, and in many other ways, so that judgment of the net economic advantage of an innovation and of the adequacy of the firm's resources to adopt and implement it may well differ from firm to firm. A particular innovation may have great advantage for one firm but not for another. The decision by a firm not to adopt should be viewed in the context of its particular needs and opportunities. A decision not to adopt may be reconsidered as the innovation is improved or as conditions in the firm's situation or environment change. On the other hand, a decision to adopt may be reversed if problems develop in the implementation of the innovation. It is not possible to determine whether the rate of diffusion of an innovation is too slow or too fast, unless one knows the causes for firms' decisions to adopt or not to adopt. It is possible that the benefits of an innovation do not warrant adoption at a particular time, or that it has certain disadvantages. Innovations when first introduced are often relatively crude and unsuited to many of their ultimate uses. They may offer little or no relative advantage over existing technology and sometimes have relative disadvantages. (Rosenberg, 1978, p. 5)

Gold reports that since adoption decisionmaking proceeds in the face of great uncertainty, it frequently relies on the personal values of those involved instead of on formal calculation of expected economic benefits. He found decisions to adopt were often based on expected physical input-output improvements, while simply assuming equivalent economic benefits. (p. 17)

The spread of innovations involves more than the acquisition of new capital equipment or a new product. It often involves considerable adjustment to the innovation in terms of training workers and adjustment of the production line. Gold points out that it may take years of working with the new process and fine tuning to get performance superior to the old. There has been little consideration of post-adoption processes, such as the use, maintenance, and modification of the innovation. This is unfortunate because it is through these processes that the firm obtains the benefits of the innovation. Mansfield has investigated the rate at which firms substitute new technology for old; this will be discussed later in this section.

D. Factors Affecting the Rate of Diffusion

Nelson, Peck, and Kalachek have done a substantial amount of research to find out what factors affect the rate of diffusion of an innovation. They considered that three factors affect the speed of diffusion:

> (1) The long run advantage of the new product or process over older ones; (2) the transition costs and frictions, on the one hand, and the costs and dangers of maintaining the status quo, on the other; and (3) the uncertainty about the superiority of the new product and the ease or difficulty of overcoming these uncertainties, (p. 100)

This was supported by Mansfield who concluded on the basis of a study of 12 innovations that the rate of diffusion is determined in large part by four factors: "The extent of the economic advantage of the innovation over older methods or products, the extent of the uncertainty associated with using the innovation when it appears, the extent of the commitment required to try out the innovation, and the rate at which the initial uncertainty regarding the innovation's performance can be reduced." (1968 A, p. 133) Mansfield constructed a simple mathematical model based on the hypothesis that the probability that a firm will introduce a new technique increases with the proportion of firms already using it and the profitability of doing so, but decreases with the size of the investment required. He found that this model explained almost all the observed variation in rates of diffusion for the 12 innovations he studied. (p. 121)

Subsequent studies by Mansfield, Hsia, and others indicate that the original model is quite useful for predicting the rate of diffusion for other innovations in this and in other countries. Results suggest that the model can also be used to explain the growth over time in the percentage of industry output produced with a new process and the increase over time in the percentage of new machine tools purchased that have numerical controls. (1977, p. 206)

The three factors—relative advantage, uncertainty and uncertainty reduction, and investment required—will be discussed briefly, and then some of the other factors thought to affect the rate of diffusion of innovations in industry.

1. RELATIVE ADVANTAGE

Nelson, Peck, and Kalachek stated:

> If a new product is better or cheaper than an old one, or meets a want that could not be met before at a reasonable price, it eventually will be used in all or most situations where it has positive net value. If it is very desirable and profitable, it will be adopted faster than if it is only marginally profitable. (p. 100)

Many authors, including Mansfield above, have equated relative advantage with profitability of the innovation. Ways in which an innovation may be relatively more profitable than the technology which it is replacing include reduction of unit costs for production, increased demand for the product due to improved quality, or increased price for the product because of improved quality. Other authors have pointed out that relative advantage is in the eyes of the adopting firm and therefore depends on the firm's needs and opportunities. For some firms, relative advantage may be simply the prestige of being first, while for others it may be less dependence on expensive raw materials or lower emission of regulated pollutants.

2. INVESTMENT REQUIRED

As noted above, Mansfield found that the rate of diffusion was adversely affected by the size of the investment required to adopt the innovation. Nelson, Peck, and Kalachek pointed out that:

> Capital stock, education, and organizational form all reflect existing technology, and generally must be altered to suit new developments.
>
> The necessity of acquiring new physical capital frequently makes rapid transition uneconomic. Where the innovation is a new consumer good performing a radically new function, or is in a product field for which demand is growing rapidly, or is equipment used in an expanding field, there is no major competition with existing capital. If a new consumer or producer durable competes strongly with existing durable goods—and must win its way largely by replacing them—there is an element of friction. . . . The user's comparison is the purchase price of the invention plus its operating cost against the operating cost of the old good plus resale value. The higher the purchase price, the greater must be the operating cost advantage to make replacement economical. As an existing stock of capital ages and deteriorates replacement becomes progressively economical but again, the higher the purchase price, the slower the initial replacement will proceed, at the onset.
>
> Likewise, adoption will be delayed if the new technique requires new kinds of knowledge or patterns of behavior which are costly in terms of resources, effort, or time. (pp. 100–101)

3. UNCERTAINTY

Nelson, Peck, and Kalacheck argued that the uncertainty about the advantages of an innovation and the ease with which that uncertainty was removed determine the rate of diffusion of an innovation. They elaborated:

> Some innovations, representing only marginal modifications from existing equipment, may be relatively easy to demonstrate and evaluate. For major innovations it may be considerably more difficult for sellers to demonstrate that a potential user could effectively and beneficially adopt the new technique or product, or for potential users confidenttly to make ther own evaluation. . . .
>
> These factors influencing uncertainty resolution appear to play a major role in determining the pace of adaptation: (1) The extent to which an innovation may be tried out on a small scale; (2) the extent to which potential users include

a group with education and training which permits information about the new product to be decoded and understood and experiments to be performed effectively and confidently; and (3) the strength of the information dissemination system. (p. 103)

Early users of an innovation generally try it out on a limited or experimental basis when possible. When performance is proven, they may increase their usage of the innovation. To the extent limited trial is possible, some uncertainty can be resolved and adoption will proceed more smoothly. Where, as in catalytic cracking, the decision is all-or-nothing, great caution will be exercised and the rate of diffusion may be slowed.

Several studies indicate the importance of technically sophisticated people in or available to the firm who are capable of evaluating the new technology. Mansfield et al. found that an industry's R&D expenditures as a percentage of sales were a significant determinant of its rate of diffusion. This suggests that R&D in the industrial firm is more than an invention-producing activity; it may also facilitate adoption of innovations originating outside the firm. Mansfield stated:

R&D provides the firm with a window opening on various parts of its environment. For example, it allows the firm to communicate more readily with the scientific and technological community, and to understand and evaluate other firms' innovations more quickly and more accurately. Also, it sometimes is a device to recruit and train people who eventually will move on to general management. Given these functions of R&D, it is not surprising that more R&D-intensive industries tend to accept innovations more rapidly than others. (1977, p. 209)

Other groups that may affect the rate of diffusion are organizations with direct interest in rapid acceptance such as the producing firm's sales and advertising departments, technical professional associations, trade associations, industry publications, and Government agencies such as the Agricultural Extension Service.

As noted above, Mansfield's model of diffusion was based on the assumption that the probability of a firm's adoption would be positively related to the number of firms that had already adopted the innovation, that being a measure of how much uncertainty has been reduced, since uncertainty is reduced through experience with the innovation.

4. EXPECTED FUTURE RATE OF INNOVATION

The early versions of an innovation are frequently more expensive and do not perform as well as later versions. If a firm believes that improvements will be forthcoming in the near future, it may be rational to delay adoption. It may also be wise to delay making a change if it is believed that a completely different, competitive innovation may be introduced in the near future.

5. BOTTLENECKS IN SUPPLY

Rosenberg has suggested the importance of a well-developed capital goods sector to the diffusion of innovations. The speed of diffusion of a process innovation, for example, depends on the ability of the capital goods sector to provide the machinery and components manufactured to the proper specifications. In the past, examples have occurred of

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innovations that were not widely adopted because precisely machined parts were not available. However, Nelson, Peck, and Kalacheck concluded that "there is little evidence that bottlenecks on the supply side have been important" in developed nations such as the United States. (p. 105) At any rate, there has been relatively little study of the relations between suppliers and users in the diffusion of innovations.

6. INDUSTRIAL CONCENTRATION

Nelson, Peck, and Kalacheck hypothesized that the pressure to adopt innovations rapidly will be greater in competitive industries than in sheltered industries. Empirical evidence provided by Mansfield et al. seems to support this hypothesis. They found that, in the case of numerically controlled machine tools, the rate of diffusion was higher in less concentrated industries. Both the number of firms in the industry and the inequality of firm sizes had a significant effect on the rate. (1977, p. 208)

7. OTHER FACTORS AFFECTING THE RATE OF DIFFUSION

Rosenberg has suggested additional factors that may affect the rate of diffusion. Sometimes there is a need for "complementary" innovations to exploit the full potential of the original innovation. For instance, the invention of steel rails and air brakes was important for the development of the railroad industry. When these "complementary" innovations do not occur, the original innovation may not be widely used.

Rosenberg also noted that the introduction of an innovation does not automatically cause the demise of existing technologies with which it competes. The old and new technologies frequently coexist for some period. In the early stages the new technology may still have some disadvantages with regard to the old technology. At the same time, the old technology may continue to undergo improvements, which may be stimulated by the competition from the new technology. Improvements in the old technology may be more preferable to some firms than taking a chance with a promising but unproven new technology.

There exists some evidence that in cases where governmental regulations are a factor, they may significantly affect the rate of diffusion of technological innovations, Lakhani found the rate of diffusion of pollution-reducing innovations to be positively associated with environmental protection expenditures by State governments. These findings are, however, preliminary and have not been confirmed by a body of research in this area.

E. Factors Affecting the Firm's Propensity To Adopt

There have also been studies of the factors that determine whether a particular firm will adopt an innovation rapidly or slowly. Mansfield summarized the results of this research:

> Among industrial firms, the size of a firm and the profitability of its investment in the technique seem to be directly related to the speed with which it begins using it. However, there is no evidence that a firm's speed of response is related to the firm's rate of growth, profit level, liquidity, profit trend, or age of a firm's management. (1968 A, p. 133)

There appears to be disagreement on whether size of firm is associated with speed of adoption. Mansfield's more recent research on numerical control machine tools confirmed that within a given industry larger firms tend to be quicker than the smaller ones to begin use. (1977, p. 209) Utterback, on the other hand, stated:

> There is no evident relationship between firm size and speed of adoption of innovations. Larger firms appear to lead in some industries, while smaller and medium-sized firms lead in others. Nor does leadership in adoption appear to be concentrated in particular firms in the few industries for which data are available. (p. 625)

The reason for the disagreement may lie in the cost of innovations relative to firm resources. In the chemical industry, large firms were found to adopt the more costly innovations more rapidly than small firms, but this relation was not as strong for less costly innovations. (Mansfield, 1977, p. 209) Some innovations are too costly to be adopted at all by small firms. Thus, although large firms may be quicker to adopt innovations, it does not necessarily indicate that they are more "innovative" than small firms.

F. Intrafirm Rates of Diffusion

The process of diffusion does not end with the initial adoption by user firms. Most firms will try an innovation on a limited basis at first, and then, if satisfied, will convert more and more of their facilities to the new technology. The rate at which firms convert to the new process is another important determinant of the rate at which the innovation diffuses. Mansfield studied 30 randomly chosen railroads to learn the number of years that elapsed between the time when diesel locomotives were 10 percent of the total locomotive stock and the time when they were 90 percent. He found a wide variation, from 3 years to 14 years or more. The average length of time required was 9 years. The results of an econometric study showed that about two-thirds of the variation could be explained by the following factors: Profit expectation of the investment in diesel locomotives, the date when a firm began to use diesels, the size of the firm, the age distribution of its steam locomotives, and a firm's initial liquidity. The higher the profitability expected, the speedier the conversion. Small firms, once they began, were quicker than large firms. The intrafirm rate of diffusion was faster for firms that were later to begin using the innovation, that had older equipment, and that were more liquid. (1968A, p. 125–126)

Subsequent research by Mansfield et al. revealed that the rate of intrafirm diffusion of numerical control machine tools was also inversely related to size. But that may be in large part due to the flexible, "batch" orientation of numerical control machines, which makes them relatively more attractive to small firms than to large firms, which tend to use more specialized equipment. For cases in the chemical industry where conversion was not instantaneous, the rates seem to be inversely related to a firm's share of the market for the relevant product. Thus, Mansfield summarized: "With regard to all the innovations studied (in the chemical and other industries) where intrafirm rates of diffusion vary among firms, there is a tendency for firms with large shares of the market to have relatively low intrafirm rates of diffusion." (1977, p. 209)

G. Diffusion of Product Innovations

Most research on the diffusion of innovations has studied process innovations, as opposed to product innovations. Recently, one of Mansfield's colleagues provided some evidence on the rate of diffusion of 29 new products in the chemical industry. The results indicated that the profitability of the innovation, the size of the investment required to produce the innovation, and the existence and duration of patents had significant effects on the rate of diffusion. These findings demonstrated the basic similarity between the diffusion process for products and processes in the chemical industry. (1977, p. 210) In that industry, in addition to expected profitability of the innovation and the investment required, the existence of patents may affect the rate of diffusion if they are used to block adoption by competitors.

VI. The Industrial Innovation System

An instructive way of looking at innovation is to view it as part of a dynamic system composed of various institutions and activities, with flows of information, people, and resources occurring between the elements of the system. The concept of a "technology delivery system," including subsystems that perform R&D, manufacture and distribute products, and finance innovation activities, was used by the National Academy of Engineering in 1973 to represent the complex processes by which scientific knowledge is applied. Similarly, innovation is characterized as an "ecology" consisting of the phases of innovative activity occurring within social, cultural, political, and economic environments. (Kelly and Kranzberg) One of the advantages of this type of approach is that it points out areas of specialization and overlap between institutions and interactions between institutions and functions. This section of the paper will describe some of the major institutions in the industrial innovation system.

A. R&D Performing Institutions

In 1978 total R&D spending in the United States was estimated to be $47.3 billion. This does not represent all innovation expenditures, because the introduction of new products and processes requires large investments in tooling, manufacturing start-up, and marketing start-up. Estimates of the proportion of innovation costs represented by R&D range from 10 percent to 59 percent. (Stead) In 1977, an estimated 571,000 scientists and engineers were employed in R&D in the United States, surpassing the previous peak of 557,000 set in 1969. (NSF, 1978 A, pp. 4, 17)

The growth of organized R&D in the 20th century has been accompanied by the decline of the importance of independent inventors. Although individuals are still important contributors of inventions in some industries, there has been a shift since the early part of this century toward a larger contribution from inventors associated with corporate R&D.

The major R&D performing institutions are: industrial R&D laboratories, universities, nonprofit laboratories, and Government laboratories. Each will be discussed briefly in turn.

1. INDUSTRIAL R&D LABORATORIES

Private industry is the largest performer of R&D in the United States, performing 70.3 percent of the R&D, or $33.2 billion in 1978. About two-thirds of the scientists and engineers engaged in R&D are employed by industry. (NSF, 1978 A)

The growth of industrial R&D in the 20th century has been phenomenal in terms of numbers of laboratories, expenditures, and people. During the last 60 years most large firms have set up full-time, specialized R&D departments. At the turn of the century the number of industrial R&D laboratories was small; by 1975 there were more than 6,600 listed in the directory of Industrial Research Laboratories of the United States. In 1921 there were less than 20,000 corporate R&D personnel. In 1977 industry employed 380,400 scientists and engineers in R&D. In 1921 only $150 million was spent on R&D in the United States, compared to $47.3 billion in 1978.

In the 18th and 19th centuries, technical progress was largely the result of direct observation and small-scale experiments, improvements that could be made by mechanics and engineers who often did not possess extensive formal education. The growth of industrial R&D laboratories reflects the organization and specialization of this kind of activity and is associated with three main changes, according to Freeman:

> (1) The increasingly scientific character of technology. This applies not only to chemical and electronic processes but often to mechanical processes as well. A formal body of "book learning" is usually necessary now for those who wish to advance the state of the art, as well as practical experience.
>
> (2) The growing complexity of technology, for example, the partial replacement of "batch" and "one-off" systems of production by "flow" and "mass" production lines. It is expensive and sometimes almost impossible to use the normal production line for experiments in large-scale plants. The physical separation of experimental development work into specialized institutions was often a necessity in such cases. The sheer number of components in some processes and products has similar effects in prototype and pilot plant work.
>
> (3) The general trend towards division of labour, noted by Adam Smith, which gave some advantages to the specialized research laboratories, with their now highly trained manpower, information services and scientific apparatus. (p. 24)

The increasing complexity of the technology is also said to have contributed to increasing costs and duration of innovation projects, resulting in the need for public involvement. Freeman gave the example of nuclear energy:

> The need for such massive public investment arose because nuclear engineering processes carry to an extreme degree all the tendencies which have been discussed. . . . The very heavy costs and long gestation period arose from the extraordinary complexity of the design problems, involving new materials, instruments, components and equipment of all kinds to satisfy the exacting requirements and safety standards of the new technology. At every stage intimate collaboration was necessary between nuclear engineers and scientific research teams investigating fundamental problems, so that large R&D groups were essential. (p. 73)

Industrial R&D is "concentrated" in three respects. First, industrial R&D is concentrated in a relatively small number of large firms. Second, it is concentrated in a few industries and product lines. Third, R&D is concentrated on short reach, applied work. (There appears to be a shift toward even more concentration on short-term work.)

Although the total number of U.S. companies engaging in R&D is estimated to exceed 10,000, the 1,200 companies with employees of more than 1,000 account for about 95 percent of total R&D expenditures. Within these 1,200, 100 firms account for about 80 percent of the overall total, and the top 8 firms represent about 35 percent. (Shapley and Phillips, p. 57)

The five leading R&D-performing industries—aircraft and missiles, electrical equipment and communication, machinery, chemicals, and motor vehicles—spent about 80 percent of total industrial R&D funds in 1976. Companies in the first two industries accounted for nearly one-half of the all-industry total. Historically, there has been little change in this measure of concentration. (NSF, 1978 B)

In 1977, 4 percent of industrial R&D expenditures went for basic research. Only 185 of the 494 R&D-performing firms with employment greater than 5,000 in 1975 performed industrial basic research. The chemical industry accounted for 41 percent of basic research expenditures in 1976. Industry has been performing approximately 15 percent of national basic research in recent years. (Ibid.)

The Federal Government supported about 35 percent of the R&D performed in industry in 1978; the remainder was financed by industry's own funds. Prior to World War II, the Federal Government played a small role in industrial R&D; during and after the war Federal involvement grew dramatically. The level of government support for industrial R&D declined from its peak in the late 1960's with the end of the Vietnam war and the decline of the NASA space effort.

Much industrial R&D is performed for, and sold to, the Federal Government in the form of hardware, studies, or services. Shapley and Phillips pointed out:

> In defense and space technology-oriented companies . . . R&D itself is a big business; for such companies, R&D sales can represent a large fraction of total business, and maintaining a steady stream of Government R&D contracts becomes a major corporate objective. (p. 55)

Industries vary, however, in the extent to which they perform R&D for the Federal Government. Aircraft and missiles, and electrical equipment and communications are the most heavily involved, and some R&D-intensive industries such as chemicals and pharmaceuticals perform little federally funded R&D.

Shapley and Phillips further described the nature of government R&D performed in industry:

> They are developing weapons systems, space hardware, energy technologies, and new medicines; they are doing applied research and development on new technologies, new equipment, and new instruments; and they are building experimental and demonstration plants and Federal R&D facilities. They are doing an enormous volume of paper studies of new concepts and design options, sometimes backing them up with experimental tests of crucial features. They are providing the Government with a wide range of support services for Federal research, development, test, and evaluation activities, ranging from full responsibility for the operation of laboratories and test centers to the provision of more specialized analysis, computational and other technical services. Industry is also performing some federally funded basic research, but the amount is relatively small; less than 2 percent of all Federal R&D performed by industry and less than 6 percent of all federally funded basic research. (p. 58)

This is different from the R&D funded by industry itself, where R&D is a cost to be recouped, not by prompt reimbursement from a Federal customer:

. . . but out of income earned from sales in the future. While Federal tax laws permit company R&D expenditures to be written off as a current expense, the companies themselves must regard R&D as one of several investment alternatives for meeting future company objectives. R&D in this mode is a cost of doing and staying in business; as such, it has to stand the same scrutiny as all the other costs that enter into the balance sheet. (p. 55)

About 7 percent of U.S. company-funded R&D is performed overseas. (NSF, 1979) This is the same percentage level as the 1965–1966 period. (Creamer; Mansfield, Teece, and Romeo) Foreign R&D expenditures of U.S. firms grew rapidly through the 1960's and early 1970's, when they reached about 10 percent, and have slowed in growth since then, according to the limited data available. In the 1974–1977 period, the foreign R&D expenditures of U.S. firms grew slightly faster than their domestic R&D expenditures. The primary reason given for foreign R&D is the need to tailor technology to special design needs of foreign markets and operations. The percent of a firm's R&D expenditures that are performed abroad is a function of the percentage of the firm's sales derived from foreign subsidiaries. Fifteen percent of the major U.S. industrial R&D performers maintain foreign laboratories, but these firms account for approximately one-half of U.S. company-funded R&D spending. Foreign R&D spending by U.S. firms is heavily concentrated in Canada and Western Europe. The R&D done in foreign laboratories tends toward development, rather than research, toward improved products and processes, rather than new products and processes, and toward short-term projects, rather than long-term projects. It is usually in the same product fields and scientific fields as that of the parent firm. Some of the R&D performed abroad has commercial applicability to U.S. operations.

There is increasing concern about apparent trends in industrial R&D. The overall level of industrial R&D expenditures has stagnated in constant dollars since the late 1960's, due primarily to the decline in Federal support for industrial R&D. Industrial R&D funded by industry itself has increased since that time but not enough to offset the Federal decrease. Basic research in industry has declined. Since 1967, industry-funded basic research has declined 10 percent in constant dollars, while applied research and development together have increased 42 percent. (Shapley and Phillips, p. 61) Moreover, there are claims that industrial R&D is increasingly focusing on short-term objectives and existing products. Mansfield has provided tentative evidence that most industries reduced the proportion of their R&D expenditures for relatively risky projects in the period 1967–1977, and some industries cut the proportion going for relatively long-term projects. (n.d., pp. 14–15) Some of the causes that have been suggested are: economic and political uncertainty, competing demands for capital investment funds, government regulatory requirements, and an already heavily exploited science base. The concern about trends is based on the belief that industrial R&D and innovation are important contributors to economic growth and productivity and to improving the quality of life. Although they admitted that the statistical support for the existence of a decline in innovation and its purported causes is weak, Shapley and Phillips concluded: "There can be no doubt that there has been a major new emphasis on 'defensive' R&D in industry in recent years." (p. 63)

2. UNIVERSITIES

The intellectual environment of the university or college setting seems particularly appropriate to the conduct of basic research. Thus, it is not surprising that universities and colleges are the major performers of basic research in the country, accounting for over one-half of the national total. These institutions devote more than three-quarters of their R&D efforts to basic activities. Generally, academic R&D activities are not closely linked to a facility that uses their results directly, such as a manufacturing plant. The direction of this research is largely determined by the interests of the scientific community and generally coupled to graduate instruction. However, some university R&D is more closely related to establishing the science base under particular technologies. The agricultural experimentation stations and research associated with medical school hospitals are prominent examples. Basic research in universities contributes to industrial innovation by adding to the pool of scientific knowledge which may be used by industry in the development of new and improved products and processes.

Federal agencies contribute about two-thirds of the funds used for R&D performance by universities and colleges. Universities and colleges also perform research and development for industrial firms, State and local governments, and nonprofit organizations. Together with universities' own funds, these sources account for the remaining one-third of R&D funds expended by universities and colleges. (NSF, 1978 A)

3. NONPROFIT R&D LABORATORIES

In 1978, nonprofit institutions other than universities and colleges performed $1.5 billion of R&D or about 3 percent of the total. Nonprofit institutions include research institutes, philanthropic foundations, professional and technical societies, academies of science, voluntary as well as State and local hospitals, science museums, zoological parks, botanical gardens, and arboretums. These organizations pursue widely differing programs in promoting science, including R&D performance, funding, information dissemination, and education. Despite relatively limited R&D expenditures, they have accounted for significant contributions in many fields. For instance, the Xerox copier was developed initially by the Battelle Memorial Institute. (NSF, 1978 A)

4. GOVERNMENT LABORATORIES

In addition to funding R&D in other sectors, the Federal Government is also a large performer of R&D. Federal intramural R&D performance was expected to amount to about $6.6 billion or about 14 percent of the 1978 R&D total. This represented about 28 percent of

Federal funds spent on R&D. (NSF, 1978 A) Technologies developed in government laboratories have occasionally been transferred to the private sector for manufacture and civilian applications, e.g., radar, nuclear power, and aircraft.

B. Manufacturers and Distributors

Having briefly described the major R&D performing institutions in the United States, consider the institutions that manufacture and distribute products. Without these institutions it would be impossible for innovations to spread, hence, there would be little incentive to develop them.

The transition from R&D to production is an important one. Research has shown that innovation goes more smoothly when the R&D is done by the same organization that manufactures the innovation. Moreover, within the firm, good working relations between the R&D and production departments are important to innovation. As Mansfield indicated:

> The production people must produce the new item emerging from the R&D department. Often there are considerable problems in translating jobs to be done from the language and methods appropriate to R&D engineers into terms that are useful to draftsmen, production engineers, production supervisors, and ultimately, operatives. Moreover, the linguistic and communication difficulties are often compounded by problems of status and power. For example, the development engineers may tend to look down on the production people. Whether the results of the R&D department come to fruition may be dependent on the production staff as well as the marketing staff. It is not uncommon for good ideas stemming from the R&D department to be blocked by production managers who feel threatened by the problems involved in the change. (1968 A, pp. 87–88)

The traditionally high rate of innovation in American industry is closely linked with the high level of industrial development in this country. A very complex industrial system has developed where much of the manufactured output is used in other manufacturing processes and not by the final consumer. Most industrial innovation goes on in the capital goods sector, not consumer goods. Most industrial firms are served by supplier firms and capital equipment firms; they, in turn, provide products to a customer firm. There is much interaction between buyer and seller firms. Often a firm's suppliers or customers will be involved in the innovation that goes on within the firm. Customers may demand new products and suppliers may provide new products. For example, in the textile industries the suppliers have been the source of many innovations:

> The textile mill products industry itself has done little R&D, yet has experienced gains in productivity faster than the average industry, with significant improvements in products. The principal reason is that supplying industries—particularly chemicals—have originated many new products for the textile mill products industries to use or process, and, in addition, have provided considerable technical assistance. (Nelson, Peck, and Kalacheck, p. 75)

Peck has shown the importance of equipment makers to technological change in the aluminum industry.

The interaction between buyer and seller firms is responsible for much of the spread of innovations and their economic impact. Rosenberg discusses this phenomenon in detail:

. . . Many of the benefits of increased productivity flowing from an innovation are captured in industries other than the one in which the innovation was made. As a result, a full accounting should, in principle, encompass all of these inter-industry relationships. In practice it is difficult to identify, much less measure, these benefits. Partly this is due to the fact that industrial development under a dynamic technology leads to wholly new patterns of specialization both by firm and by industry, so that it is impossible to compartmentalize the consequences of technological innovation within any set of established industrial boundaries. . . . The ways in which technological changes coming from one industry constitute sources of technological progress and productivity growth in other industries defy easy summary or categorization. (1976, p. 27)

C. Innovation Financing Flows

As noted in the previous discussion, most R&D performing institutions also provide financing for R&D within their own institutions as well as in other institutions. An overview of the flows of financial resources for R&D in 1978 is provided by tables 2–5. (NSF, 1978 A) These tables do not include funding for non-R&D innovation expenses.

Table 2 indicates that industry receives one-third of its R&D financing from the Federal Government and finances the other two-thirds itself. The private firm finances the later stages of innovation—the tooling, manufacturing start-up, and marketing start-up—generally from retained earnings, but sometimes with loans or equity debt. There is little information about the proportion of innovation expense financed through capital markets, but it is probably small, because the uncertainty involved in innovation projects is too high for most financial institutions to undertake. (Freeman, p. 225)

TABLE 2.—INTERSECTORAL TRANSFERS OF FUNDS USED FOR PERFORMANCE OF RESEARCH AND DEVELOPMENT:[1] 1978 (ESTIMATED)

[Dollar amounts in millions]

Sources of funds	Performers: Federal Government	Industry[2]	Universities and colleges[3]	Associated FFRDC's[4]	Other nonprofit institutions[2]	Total	Percent distribution, sources
Federal Government	$6,565	$11,750	$3,075	$1,375	$1,050	$23,815	50.4
Industry		[5]21,500	150		130	21,780	46.0
Universities and colleges			[5]1,000			1,000	2.1
Other nonprofit institutions			360		[5]340	700	1.5
Total	6,565	33,250	4,585	1,375	1,520	47,295	
(Universities and colleges + Associated FFRDC's)			5,960				
Percent distribution, performers	13.9	70.3	9.7	2.9	3.2		100.0
(Universities and colleges + Associated FFRDC's)			12.6				

[1] All data are estimated from reports by performers.
[2] Expenditures for federally funded research and development centers (FFRDC's) administered by both industry and by nonprofit institutions are included in the totals of their respective sectors. FFRDC's are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.
[3] Includes agricultural experiment stations.
[4] Federally funded research and development centers (FFRDC's) administered by individual universities and colleges and by university consortia.
[5] Includes State and local government funds.

Source: National Science Foundation.

TABLE 3.—INTERSECTORAL TRANSFERS OF FUNDS USED FOR PERFORMANCE OF BASIC RESEARCH:[1] 1978 (ESTIMATED)

[Dollar amounts in millions]

Sources of funds	Performers: Federal Government	Industry[2]	Universities and colleges[3]	Associated FFRDC's[4]	Other nonprofit institutions[2]	Total	Percent distribution, sources
Federal Government	$975	$225	$2,265	$410	$315	$4,190	69.3
Industry		[5] 750	85		60	895	14.8
Universities and colleges			[5] 600			600	9.9
Other nonprofit institutions			215		[5] 145	360	6.0
Total	975	975	3,165	410	520		
			3,575 (universities and colleges plus associated FFRDC's)			6,045	
Percent distribution, performers	16.1	16.1	52.3	6.8	8.7		100.0
			59.1 (universities and colleges plus associated FFRDC's)				

[1] All data are estimated from reports by performers.
[2] Expenditures for federally funded research and development centers (FFRDC's) administered by both industry and by nonprofit institutions are included in the totals of their respective sectors. FFRDC's are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.
[3] Includes agricultural experiment stations.
[4] Federally funded research and development centers (FFRDC's) administered by individual universities and colleges and by university consortia.
[5] Includes State and local government funds.

Source: National Science Foundation.

TABLE 4.—INTERSECTORAL TRANSFERS OF FUNDS USED FOR PERFORMANCE OF APPLIED RESEARCH:[1] 1978 (ESTIMATED)

[Dollar amounts in millions]

Sources of funds	Performers: Federal Government	Industry[2]	Universities and colleges[3]	Associated FFRDC's[4]	Other nonprofit institutions[2]	Total	Percent distribution, sources
Federal Government	$2,285	$1,500	$675	$460	$365	$5,285	49.3
Industry		[5] 4,750	55		45	4,850	45.2
Universities and colleges			[5] 340			340	.3
Other nonprofit institutions			120		[5] 130	250	.2
Total	2,285	6,250	1,190	460	540	10,725	
			1,650 (universities and colleges plus associated FFRDC's)				
Percent distribution, performers	21.3	58.3	11.1	4.3	5.0		100.0
			15.4 (universities and colleges plus associated FFRDC's)				

[1] All data are estimated from reports by performers.
[2] Expenditures for federally funded research and development centers (FFRDC's) administered by both industry and by nonprofit institutions are included in the totals of their respective sectors. FFRDC's are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.
[3] Includes agricultural experiment stations.
[4] Federally funded research and development centers (FFRDC's) administered by individual universities and colleges and by university consortia.
[5] Includes State and local government funds.

Source: National Science Foundation.

TABLE 5.—INTERSECTORAL TRANSFERS OF FUNDS USED FOR PERFORMANCE OF DEVELOPMENT:[1] 1978 (ESTIMATED)

[Dollar amounts in millions]

Sources of funds	Performers: Federal Government	Industry[2]	Universities and colleges[3]	Associated FFRDC's[4]	Other nonprofit institutions[2]	Total	Percent distribution, sources
Federal Government	$3,305	$10,025	$135	$505	$370	$14,340	47.0
Industry		[5]16,000	10		25	16,035	52.5
Universities and colleges			[5]60			60	.2
Other nonprofit institutions			25		[5]65	90	.3
Total	3,305	26,025	230	505	460	30,525	
			735 (universities and colleges plus associated FFRDC's)				
Percent distribution, performers	10.8	85.3	.8	1.6	1.5		100.0
			2.4 (universities and colleges plus associated FFRDC's)				

[1] All data are estimated from reports by performers.
[2] Expenditures for federally funded research and development centers (FFRDC's) administered by both industry and by nonprofit institutions are included in the totals of their respective sectors. FFRDC's are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.
[3] Includes agricultural experiment stations.
[4] Federally funded research and development centers (FFRDC's) administered by individual universities and colleges and by university consortia.
[5] Includes State and local government funds.

Source: National Science Foundation.

The question of capital availability is especially critical to the start-up of new, high-technology firms. A recent study by the Charles River Associates showed that such companies are more dependent on equity capital than other small businesses. Some specialized venture capital investment companies do exist, but they do not generally fund R&D or business start-ups. (Bean et al.) Wealthy individuals and relatives are one of the largest sources of outside capital for new, high-technology companies.

The access of particular industries to capital is critical. If basic industries such as steel cannot attract sufficient capital to construct new facilities or replace equipment they will not be able to undertake significant innovation. Inability to keep up with technological change may impair the industry's competitiveness and may have broader repercussions throughout the economy. The availability of investment capital decreased in the 1970's with potentially serious implications for technological progress. This problem seems to have been partially alleviated, however, by the Tax Reform Act of 1978.

D. Information Flows

Many studies have focused upon the importance of scientific and technical information to the innovation process. In-house R&D activities are not the only source of information for innovation. Other sources are the personal experience and knowledge of scientists and engineers, scientific papers and textbooks, and operating materials and handbooks. Much information of importance to innovation is obtained from outside the firm, primarily from universities, government laboratories, and other firms. In three studies of innovation undertaken in the United Kingdom, it was found that the primary source of information inputs to industrial innovation from outside the firm were: Industry, government-funded laboratories, and universities. In all three studies, more than 45 percent of the knowledge from outside sources came from government-funded technological institutes and universities. (Pavitt and Walker) These and other studies provide considerable evidence of a positive relation between successful innovation by industrial firms and their use of external information sources. (NSF, 1978 D, p. 2)

Firms have an incentive to rely on their own resources and information because they desire to maintain a monopoly position with respect to the technological know-how. A tendency to rely on internal information becomes more pronounced as the innovation approaches commercialization. (Myers and Marquis) Since effective use of outside information is important for successful innovation, excessive self-reliance may be self-defeating, however.

Existing studies of information inputs to innovation are mainly in R&D intensive industries. In contrast, a Dutch study of materials handling industries "found that neither innovative nor non-innovative firms make much use of external sources of knowledge, either from universities or from Government-funded institutes and laboratories." (cited in Pavitt and Walker, p. 24) Moreover, in industries where the rate of technological change is slow, the firm may have less need for information about its external environment. (Blandin and Brown, Taylor and Utterback)

Small firms make less use of outside sources of scientific and technological information than large firms, because they have fewer outside contacts and are less well equipped to monitor and use written scientific and technological information. Studies in England and France found, among firms making significant innovations, that a higher percentage of innovative ideas originated within the firm—as opposed to outside the firm—in small firms than in large firms. (Pavitt and Walker, p. 24)

E. The Policy Environment

Industrial firms operate within an environment of public policies that may affect their incentive and ability to innovate. Although the primary objectives of most public policies do not concern industrial innovation, they frequently have unintended impacts because they modify institutions and incentives involved in innovation. Some unintended policy effects are undoubtedly important, such as general economic policies that affect the future outlook for return on investments. Concern has been expressed that Federal policy is becoming a major obstacle to industrial innovation, especially tax policy and health, safety, and environmental regulations. (NSF, 1976) President Carter's Domestic Policy Review of Industrial Innovation was initiated in response to such concerns. Unfortunately, the research base in this area is weak and little is known about how Government policies affect industrial innovation. This broad and complex area is very important for innovation policy and further research is urgently needed.

The patent system deserves special mention because it is so closely associated with invention and innovation. The objective of the patent system is to foster technological progress. It does this by granting a temporary monopoly (17 years) for inventions so that the inventor will have an incentive to commercialize it without fear that competition will immediately take away the profits. The temporary monopoly is granted in exchange for the publication of the invention and the information necessary to reproduce it.

There is debate whether the patent system encourages innovation. Pavitt and Walker summarized some of the pro and con arguments:

On the one hand, it is argued that, in addition to encouraging invention and innovation, the patent system ensures that important scientific and technical information is not kept secret, and enables small inventive firms to be protected against big ones. On the other hand, it is argued that—in conditions of oligopoly—firms in most (if not all) industrial sectors would have an incentive to innovate with or without a patent system. In addition, the patent system results in some important information being kept secret, patent pools owned by large firms are an effective barrier to competition by new entrants, and economically and socially unjustifiable benefits accrue to innovators at the expense of imitators and consumers. (p. 37)

The importance of patent rights to innovation appears to vary from industry to industry. (NSF, 1976) Patents may be more important to small firms and independent inventors than to large firms, presumably because the former have few other ways to protect their innovations from encroachment. (Freeman) Patents also may be more important for product innovations than for process innovations because information on process innovations is more easily kept secret. (SAPPHO)

Recently there has been discussion of the weaknesses of the U.S. patent system. (Industrial Research Institute) There appears to have been a decline in the perceived utility of patents in some industries, perhaps due to these weaknesses. Evidence exists that firms are making more use of trade secrets and "black-boxing" or "potting" their technological know-how. (D. Shapley) For the period 1965–1974, domestic-origin U.S. patent applications remained essentially constant. (Department of Commerce, p. 38)

It may be wondered why the U.S. patent system grants a patent life of 17 years, when those granted by some other countries are shorter and others are longer. A longer patent life is often claimed to be a bigger incentive to invent and introduce the invention. Theoretical models indicate that, to the extent that firms respond to patent incentives, the rate of introduction of innovations increases as patent life increases. (NSF, 1976, p. 27)

VII. Innovation Time Lags

The process of innovation occurs over time. Concern that innovation does not happen fast enough frequently is acompanied by a desire to "speed up" the innovation process. For instance, in 1976 two reports commissioned by the President's Biomedical Research Panel addressed the reasons for time lags in biomedical research and how they could be shortened. The author of one of these reports stated:

Lags can be too short, too long, or just right. They are too short when their application becomes widespread before limitations and risks are fully known; they are too long when all the necessary knowledge is at hand but it is not applied to clinical medicine or surgery; they can be just right—even though the lag is long in years—when many completely unforeseen discoveries (e.g., X-rays, penicillin) are needed for the final clinical advance. (Comroe, p. 33)

A. The Concept of Innovation Time Lags

Existing studies of innovation time lags have been based on small samples of innovations and plagued with conceptual problems. Time lags in the generation of innovations appear to vary widely, with some of the variation explained by industry differences. Figure 4 is a graphic representation of the findings from several studies. (Mogee)

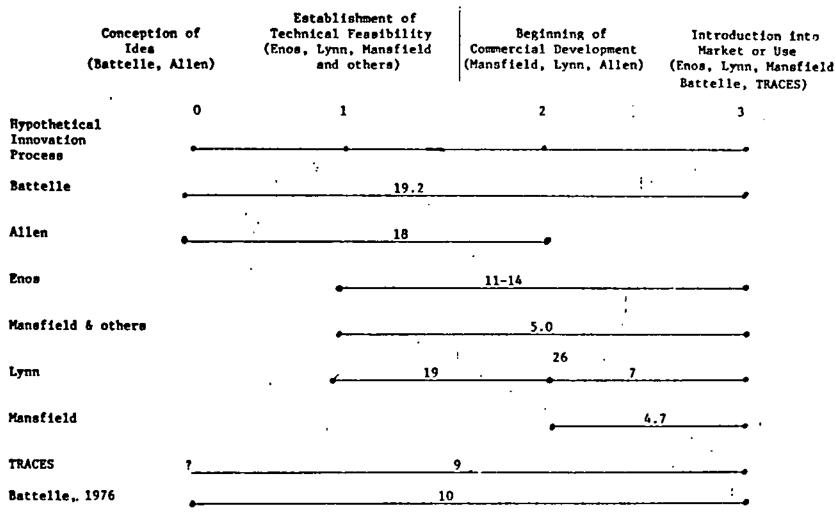

FIGURE 4.—Average Innovation Time Lags in Years

The concept of time lag rests on shaky foundations because of the multiple origins of innovations. It is usually difficult to designate a single scientific discovery or idea on which an innovation is based. In the research stage, and even up to the point of a patented invention, there may be several lines (possibly competing) that have contributed toward the successful introduction of the innovation. In practice, different researchers have assigned different lags to the same innovation.

The concept of the innovation time lag has little meaning unless it accounts for the amount and quality of effort per unit time expended and the nature of the activities being performed in any given period. In the case of innovations that take many years, there are frequently long periods when no innovative activity is going on because a technical limit has been reached; important related materials, components, or technologies have not been developed; or the economic conditions do not justify development.

Time is an important factor in the innovation process which, to some extent, may be traded off with costs. For instance, it is common practice to put more people to work on a project in order to hasten its completion. Mansfield found that a decrease in project duration was commonly associated by engineers with increased costs. (1971, p. 156) Utterback concluded that there is an adverse relationship between time and cost, and technical quality. Achieving a given technical advance in a reduced period of time generally results in much higher costs. (p. 624) Freeman, commenting upon the time-cost trade-off, noted that cost overruns are more frequent in military projects than time overruns, while the opposite is true in civilian projects. This suggests that some flexibility exists as to whether time or cost will be the governing factor in a given project.

B. Increasing or Decreasing Lags

An issue frequently addressed is whether innovation time lags have been increasing or decreasing over the years. Galbraith believes that today's technologies require increased time for development. On the other hand, innovations studied by Lynn seemed to indicate that the time required for innovation was growing shorter. Mansfield, in a study of the pharmaceutical industry, found a slight, but not statistically significant, decrease. After accounting for the effects of the source of innovation and product category through regression analysis, the date of introduction was found not to be statistically significant in determining time lag. The Battelle group concluded that their small sample of innovations provided no evidence of decreasing lag times. In fact, they pointed out that two of the most recently realized innovations had the longest time spans.

Langrish et al. provide a compelling critique of many of these studies, and argue that it is impossible to observe anything but relatively short time lags for recently conceived innovations. Our perspective when looking at recently conceived innovations allows us to identify only those innovations which have already been introduced into the market, although there may be inventions which have conceived but which will bear fruit only after the study. Langrish et al. conclude that data from existing studies are inadequate to show decreasing lag times over the years.

It is possible that different factors work in different ways. Modern marketing may have reduced waiting periods, however, invention and innovation may be more difficult and take longer these days.

C. Causes of Lags

Another issue in the study of innovation time lags is the cause of the lags and of differences in lags. Some of the research findings will be reviewed here. Lynn found that innovations creating new industries took longer than innovations developed in existing industries; consumer innovations took a shorter time than capital equipment innovations; and innovations developed with government funds took less time than those developed with private funds. Enos found that mechanical innovations took the shortest time, electrical the longest, with chemical and pharmaceutical innovations falling in between. Enos and Mansfield found that the lag is shorter when the inventor and innovator are the same.

Langrish et al. studied several factors causing delay in innovation in Great Britain. The most frequently occurring causes of delay were the failure of a related technology to be sufficiently developed and the lack of a market or expressed need. A shortage of resources was the most frequent delaying factor for innovations representing a large technological change, but was less frequent for small changes.

Comroe listed 17 causes of lags between the initial discovery and clinical application of innovations to cardiovascular pulmonary medicine and surgery. Some important causes included:

Scientific discoveries that were too early for their time—that is, not appreciated by the scientific community;

The necessity for many steps to be taken from initial discovery to clinical application and the occurrence of early, discouraging failures;

The lack of a perceived need for the application;

Lags in physician and patient acceptance and utilization; and

Lags in governmental regulatory agencies.

A 1976 Battelle study of biomedical advances concluded that the degree of interest exhibited by the biomedical research community and the presence or absence of supporting biomedical or nonbiomedical technology were the dominant factors in cases of longer-than-median duration.

Findings with respect to innovation time lags should be regarded with skepticism, based as they are on flimsy conceptual and emperical foundations. Lags are to some extent unavoidable and in many cases serve a useful function. Nevertheless, an improved understanding of the time required for innovation projects, the causes for delays, and the trade-offs between time, costs, technical quality, and unanticipated effects is certainly to be desired.

This concludes the review of knowledge about the process of technological innovation in industry. The Special Study on Economic Change, of which this paper is a part, has taken a future-oriented perspective in investigating industrial innovation and its potential impact on the U.S. economy and society. There is no guarantee that innovation will continue to function in the manner revealed in this review of existing knowledge. Alterations in the functioning of innovation are likely in view of the uncertainties that surround innovation and the changes that are occurring in many of the economic and social factors known to influence innovation. One of the chief concerns of technology policymakers today is the fear that innovation is not proceeding with the same vision and vigor as it has in the past. Yet our knowledge of the past is one of our few guides to the future. Thus, while this paper cannot predict the future, it can help policymakers deal with industrial innovation issues in the future. It is hoped that this paper will alert policymakers and analysts working with specific innovation policy proposals to the kinds of issues that should be investigated, provide them with some broad hypotheses about the likely impact of policies on innovation processes, and generally make them aware of the complexity and possible pitfalls of the area.

References

Abernathy, William J., and James M. Utterback. Patterns of industrial innovation. Technology review, v. 80, June/July 1978: 41–48. T171.M47, v. 80.

Alexander, Tom. It's time for new approaches to pollution control. In Leonard, H.J., et al. (eds.). Business and environment. Washington, Conservation Foundation, 1977, pp. 132–143. HD60.B87.

Allen, James Albert. Studies in innovation in the steel and chemical industries. New York, Augustus M. Kelley, 1968. x, 246 p. TN747.A45.

Allen, Thomas. Managing the flow of technology. Cambridge, Mass., MIT Press, 1977, 332 p. T174.3A44.
Baker, Norman R., and Dennis J. Sweeney. An assessment of modeling capability related to the process of organized technological innovation within the firm. Volume I: Executive Summary, Cincinnati, Ohio, University of Cincinnati, College of Business Administration, Department of Quantitative Analysis, November 1977. Report prepared for the Division of Policy Research and Analysis, National Science Foundation. (Grant RDA75-17332) 345 p.
Battelle-Columbus Laboratories. Analysis of selected biomedical research programs. In President's Biomedical Research Panel, Report of. Appendix B. Approaches to policy development for biomedical research; strategy for budgeting and movement from invention to clinical application. Washington, U.S. Department of Health, Education, and Welfare, Public Health Service. (DHEW publication no. (OS 76-502).) For sale by the Superintendent of Documents, U.S. Government Printing Office, 1976, p. 35-72.
———. Interactions of science and technology in the innovative process. Final report. Columbus, Oh., 1973. Prepared for the National Science Foundation under contract NSF-C667. Various pagings.
Bean, A.S., D.D. Schiffel, and M. E. Mogee. The venture capital market and technological innovation. Research policy, v. 4, October 1975: 380-408. Q180.A1R448.
Beardsley, George, and Edwin Mansfield. A note on the accuracy of industrial forecasts of the profitability of new products and processes. Journal of business, v. 51, Jan. 1978: 127-135. HF5001.J6.
Binswanger, Hans P. and Vernon W. Ruttan. Induced innovation; technology, institutions, and development. Baltimore, Johns Hopkins, 1978. HC79.T4B54.
Blandin, James S., and Warren B. Brown. Uncertainty and the management's search for information. IEEE transactions on engineering management, v. EM-24, November 1977. T56.12.
The breakdown of U.S. innovation. Business week, Feb. 16, 1976: 56-60, 65, 68. HF5001.B89.
Burns, Tom, and G. M. Stalker. The management of innovation. London, Tavistock, 1961. xxii, 269 p. HD31.B83.
Carpenter, Mark P., and Francis Narin. Utilization of scientific literature by U.S. patents. Cherry Hill, N.J., Computer Horizons, Inc., 1978. Prepared for the National Science Foundation under contract NSF PRM-7801694. 62 p.
Carter, C. F., and B. R. Williams. Industry and technical progress: factors governing the speed of application of science. London: Oxford University Press, 1957. 244 p. T177.G7C3.
Charles River Associates. An analysis of venture capital market imperfections. Final report. Cambridge Mass., Feb. 1976. xxii, 412 p. Report to the Experimental Technology Incentives Program, National Bureau of Standards, report No. NBS-GCR-ETIP 76-08).
Clarke, Thomas E. Decisionmaking in technologically based organizations: a literature survey of present practice. IEEE transactions on engineering management, v. EM-21, February 1974: 9-23. T56.12.
Comroe, Julius H., Jr. Lags between initial discovery and clinical application to cardiovascular pulmonary medicine and surgery. In President's Biomedical Research Panel, Report of. Appendix B. Approaches to policy development for biomedical research: strategy for budgeting and movement from invention to clinical application. Washington, U.S. Department of Health, Education, and Welfare, Public Health Service. (DHEW publication No. (OS) 76-502).) For sale by the Superintendent of Documents, U.S. Government Printing Office, 1976. p. 1-33.
Creamer, Daniel B., Anthony D. Apostolides, and Selina L. Wang. Overseas research and development by United States multinationals, 1966-1975. New York, The Conference Board, 1976. ix. 130 p. HC79.R4C7.
Downs, George W., Jr., and Lawrence B. Mohr. Conceptual issues in the study of innovation. Administrative science quarterly, v. 21, December 1976: 700-714. HD28.A25.
Enos, John. Invention and innovation in the petroleum refining industry. In Universities-National Bureau Committee for Economic Research. The rate and direction of inventive activity. Princeton, Princeton University Press, 1962. p. 299-322. HD69.I75U5.
Foster Associates, Inc. A survey on net rates of return on innovations. Washington, D.C., 1978. Report prepared for the National Science Foundation under contract NSF-76-22518.

Freeman, Christopher. The economics of industrial innovation. Baltimore, Penguin Books, 1974. 409 p. HC79.T4F73.

Gellman Research Associates, Indicators of international trends in technological innovation. Prepared for the National Science Foundation under contract NSF-C889. Washington, National Science Foundation, 1976. Various pages.

Gibbons, Michael, and Ron Johnston. The role of science in technological innovation. Research policy, v. 3, 1974: 220–242. Q180.A1R448.

Gilpin, Robert. Technology, economic growth, and international competitiveness. A report prepared for the use of the Subcommittee on Economic Growth of the Joint Economic Committee of the Congress of the United States. 94th Congress, 1st session. Washington, U.S. Government Printing Office, 1975. [Joint Committee Print] 87 pp.

Gold, Bela. Some shortcomings of research on the diffusion of industrial technology. In Radnor, Michael, et al. (eds.). The diffusion of innovations: an assessment. Evanston, Ill., Northwestern University, Center for the Interdisciplinary Study of Science and Technology, 1978. Prepared for the National Science Foundation, Division of Policy Research and Analysis under Grant PRA76–80388. 37 p.

Haeffner, Erik A. The innovation process. Technology review, v. 75, March/April 1973. T171.M47.

Hamberg, D. Invention in the industrial laboratory. Journal of political economy, v. 71, April 1963: 95–115. HB1.J7.

Hollander, Samuel. The sources of increased efficiency: a study of Du Pont rayon plants. Cambridge, Mass., The MIT Press, 1965. xxii, 228 p. HD9929.5.U62H6.

Hughes, Thomas P. Inventors: the problems they choose, the ideas they have, and the inventions they make. In Kelly, Patrick and Melvin Kranzberg (eds.). Technological innovation: a critical review of current knowledge. San Francisco, San Francisco Press, Inc., 1978. 408 p.

Illinois Institute of Technology Research Institute. Technology in retrospect and critical events in science. [Chicago] 1968. xiv, 104 p. Prepared for the National Science Foundation under contract NSF–C535. Commonly called the TRACES study.

Industrial Research Institute. Patents Working Group. Industrial Research Institute position statement on the U.S. patent system. Research management, v. 22, March 1979: 39–41. T175.5R4.

Isenson, Raymond S. Project Hindsight. Final report. Report to the Office of the Director of Defense Research and Engineering, 1969. National Technical Information Service, mimeo.

Jewkes, J., D. Sawers, and R. Stillerman. The sources of invention. Revised edition. New York, Norton, 1970. T212.J4 1969.

Kamien, M., and N. Schwartz. Market structure and innovation: a survey. Evanston, Ill., Northwestern University, Graduate School of Management, Managerial Economics and Decision Sciences, June 1974. 94 p. Prepared under a grant from the National Science Foundation, Office of National R&D Assessment.

Kelly, Patrick, and Melvin Kranzberg (eds.). Technological innovation: a critical review of current knowledge. San Francisco, San Francisco Press, 1978. 408 p.

Klein, Burton H. Dynamic economics. Cambridge, Mass., Harvard University Press, 1977. 289 p. HB171.K519.

Lakhani, Hyder. Diffusion of environment-saving technological change. Technological forecasting and social change, v. 7, No. 1, 1975. T174.T38.

Langrish, J., et al. Wealth from knowledge: a study of innovation in industry. New York, John Wiley & Sons, 1972. xii, 477 p. T173.5.G7 W4 1972 b.

Little, Arthur D., Inc. and Industrial Research Institute, Inc. Barriers to innovation in industry. Executive Summary. Washington, 1973. Prepared for the National Science Foundation under contracts NSF–C748 and C725.

Lynn, Frank. The rate of development and diffusion of techology. In Commission on Technology, Automation, and Economic Progress, Techology and the American economy. Appendix II. Washington, 1966. pp. 29–91.

Maclaurin, W. Rupert. The process of technological innovation; the launching of a new scientific industry. American economic review, v. 40, March 1950: 90–112. RS1.A4.

Mansfield, Edwin. Basic research and productivity increase in manufacturing. Mimeo, nd.d. (received 1979) 20 pp.

———. The economics of technological change. New York, Norton, 1968 (A) 257 p. HC110. T4M3.

———. Industrial research and technological innovation; an econometric analysis. New York, Norton, 1968 (B) 235 p. HC110.T4M32.

———, et al. The production and application of new industrial technology. New York, Norton, 1977. 220 p. HC110.T4P76.

———, et al. Social and private rates of return from industrial innovations. Quarterly journal of economics, v. 91, May 1977: 221–240.HB1.Q3.

———, et al. Research and innovation in the modern corporation. New York, Norton, 1971. 239 p. HD20.3R465.

———, Anthony Romeo and Samuel Wagner. Foreign trade and U.S. research and development. Review of economics and statistics, v. 61, Feb. 1979: 49–57. HA1.R35.

———, David Teece, and Anthony Romeo. Overseas research and development by U.S.-based firms. Economica, v. 46, May 1979: 187–196. HB1.E5.

McLaughlin, Doris B. The impact of labor unions on the rate and direction of technological innovation. n.p., University of Michigan-Wayne State University, Institute of Labor and Industrial Relations, 1979.

Mogee, Mary Ellen. Time lags in the production of technological innovations. Washington, National Science Foundation, Office of National R&D Assessment, 1976. 20 p. (Working paper No. 34.)

Mowery, David and Nathan Rosenberg. The influence of market demand upon innovation: a critical review of some recent empirical studies. Research policy, v. 80, March :April 1978: 41–46, T171.M47.

Mueller, Dennis C., and John E. Tilton. Research and development costs as a barrier to entry. Canadian journal of economics, v. 2, Nov. 1969: 570–579. HC111.C225.

Myers, Sumner, and Donald G. Marquis. Successful industrial innovations: a study of factors underlying innovation in selected firms, Washington, National Science Foundation, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1969. (NSF 69–17) 117 p. HC79.T4M92.

Myers, Sumner, and Eldon E. Sweezy. Why innovations fail. Technology review, v. 80. March/April 1978: 41–46. T171.M47.

Nason, Howard K., Joseph A. Steger, and George E. Manners. Support of basic research by industry. Washington, U.S. National Science Foundation. Division of Science Resources Studies, 1978. 61 p. Report prepared under grant NSF–C76–21517.

National Academy of Engineering. Committee on Public Engineering Policy. Priorities for research applicable to national needs. Report to the National Science Foundation. Washington, 1973. 134 pp.

National Academy of Sciences. Technology, trade and the U.S. economy. Washington, 1978. 180 p. HC110.T4T43.

Nelson, Richard. The simple economics of basic scientific research. In Rosenberg, Nathan (ed.). The economics of technological change. Baltimore, Penguin Books, 1971. pp. 148–163. Reprinted from the Journal of Political Economy, June 1959, pp. 297–306. HC79.T4R67.

Nelson, Richard, M. Peck and E. Kalachek. Technology, economic growth, and public policy. Washington, Brookings Institution, 1967. 251 p. T21.N4.

Nelson, Richard, and Sidney G. Winter. In search of useful theory of innovation. Research policy, v. 6, Jan. 1977 : 36–76. Q180.A1R448.

Pavitt, K., and W. Walker. Government policies towards industrial innovation: a review. Research policy, v. 5, Jan., 1976: 11–97.Q180. A1R448.

Peck, Merton J. Inventions in the postwar American aluminum industry. In Universities-National Bureau Committee for Economic Research. The rate and direction of inventive activity. Princeton, Princeton University Press, 1962. p. 279–298, HD69. I75U5.

Price, D. J. De Solla. Is technology independent of science? Technology and culture, v. 6, 1965: 553–568. T1.T27.

R&D spending at 683 companies: another record year. Business week, July 2, 1979: 52–72. HF5001.B89.

Radnor, Michael, et al. Research on the diffusion of innovations by organizations; a reappraisal. In their, The diffusion of innovations; an assessment. Evanston, Ill., Northwestern University, Center for the Interdisciplinary Study of Science and Technology, 1978. Prepared for the National Science Foundation, Division of Policy Research and Analysis under grant No. PRA76–80388. Various pagings.

Robert R. Nathan Associates, Inc. Net rates of return on innovations. Washington, D.C., 1978. Report prepared for the National Science Foundation under contract NSF 76–22519.
Robertson, Thomas S. Innovative behavior and communication. New York, Holt, Rinehart, and Winston, 1971. 331 p. HF5415.R554.
Roessner, J. David. Incentives to innovate in public and private organizations: implications for public policy. Prepared for delivery at the 1975 annual meeting of the Southern Political Science Association, Nashville, Tenn., November 6–8, 1975. 17 p.
———. Policy issues and policy research in public technology. Policy studies journal, v. 5, Winter 1976: 205–211. H1.P72.
Rogers, Everett, and Floyd Shoemaker. Communication of innovations. Second edition, New York, Free Press, 1971. xix, 476 p. HM101.R57 1971.
Rosenberg, Nathan. The diffusion of technology; an economic historian's view. In Radnor, Michael, et al. (eds.). The diffusion of innovations; an assessment. Evanston, Ill., Northwestern University, Center for the Interdisciplinary Study of Science and Technology, 1978. Prepared for the National Science Foundation, Division of Policy Research and Analysis under grant No. PRA76–80388. Various pagings.
———. Thinking about technology policy for the coming decade. In U.S. Congress. Joint Economic Committee. U.S. economic growth from 1976 to 1986: prospects, problems, and patterns. v.9. Technological change. 94th Congress, 2d session. Washington, U.S. Government Printing Office, 1976. [Joint Committee Print] p. 1–32.
Schmookler, J. Invention and economic growth. Cambridge, Mass., Harvard University Press, 1966. xv, 322 p. T211.S38.
Schon, Donald A. Technology and change. New York, Delacorte Press, a Seymour Lawrence Book, 1967. xix, 248 p. HD45.S355.
Science Policy Research Unit. University of Sussex. Success and failure in industrial innovation: report on Project Sappho. London, Centre for the Study of Industrial Innovation, 1972. 37 p. HD45.B69.
Shapley, Deborah. Electronics industry takes to "potting" its products for market. Science, v. 202, November 24, 1978: 848–849. Q1.S35.
Shapley, Willis H. and Don I. Phillips. R&D in the Federal budget, FY 1979. Washington, American Association for the Advancement of Science, 1978. xiv, 119 p.
Shimshoni, D. Aspects of scientific entrepreneurship. Cambridge, Mass., Harvard University, 1966. (Thesis.)
The silent crisis in R&D. Business week, March 8, 1976, pp. 90–91.
Staples, Elisabeth P., et al. Market structure and technological innovation: a step towards a unifying theory. In Baker, Norman and Dennis Sweeney (eds.). An assessment of modeling capability related to the process of organized technological innovation within the firm. V.II: Final Technical Report. Cincinnati, Oh., University of Cincinnati, College of Business Administration, Department of Quantitative Analysis, Nov. 1977. Report prepared for the National Science Foundation. Division of Policy Research and Analysis, under grant No. RDA75–17332. pp. 69–86.
Stead, H. The costs of technological innovation. Research policy, v. 5. Jan. 1976: 2–9. Q180.A1R448.
Strassman, W. Paul. Assessing the knowledge of innovations in neglected sectors: the case of residential construction. In Kelly, Patrick and Melvin Kranzberg (eds.). Technological innovation: a critical review of current knowledge. San Francisco, San Francisco Press, 1978. pp. 263–274.
Taylor, R. L., and J. M. Utterback. A longitudinal study of communication in research; technical and managerial influences. IEEE transactions on engineering management, v. EM–22, 1975: 80–87. T56.I2.
U.S. Department of Commerce. Patent and Trademark Office. Technology assessment and forecast, ninth report. Washington, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1979. iv, 186 p.
U.S. Library of Congress. Congressional Research Service. Science Policy Research Division. Science policy; a working glossary. Fourth edition. Prepared for the Subcommittee on Science, Research, and Technology of the Committee on Science and Technology of the U.S. House of Representatives. 95th Congress, 2d session, December 1978. ix, 262 p. [Committee print.]

U.S. National Science Board. Science indicators 1976. Washington, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1977. (NSB-77-1) 312 p.

U.S. National Science Foundation. Federal funds for research, development, and other scientific activities, fiscal years 1976, 1977, and 1978. Washington, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1977 (A). (NSF 78-300) 75 p.

———. National patterns of R&D resources, funds and manpower in the United States 1953—1978-79. Washington, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1978 (A) (NSF 78-313) viii, 45 p.

———. Preliminary papers for a colloquim on the relationships between R&D and economic growth/productivity. Washington, Nov. 9, 1977 (C).

———. Research and development in industry 1975. Washington, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1977 (B). (NSF 77-324) 92 p.

———. Research and development in industry 1976, technical notes and detailed statistical tables. Washington, 1978 (B). (NSF 78-314) v, 77 p.

———. Science and technology; annual report to the Congress. Washington, for sale by the Superintendent of Documents, U.S. Government Printing Office, 1978 (C) 137 p.

———. Division of Policy Research and Analysis. Scientific and technical information policies for industrial innovation: a review of research literature. Prepared for the President's Domestic Policy Review on Industrial Innovation. Washington, Dec. 1978 (D) 22 p.

———. Division of Science Resources Studies. U.S. industrial R&D abroad. Washington, U.S. Government Printing Office, April 1979. 7 p. (Its Reviews of data on science resources series. No. 33.) Q127.U6U489a.

———. Office of National R&D Assessment. Technological innovation and Federal Government policy; research and analysis of the Office of National R&D Assessment. Washington, 1976. 73 p.

U.S. Panel on Invention and Innovation. Technological innovation: its environment and management. Washington for sale by the Superintendent of Documents, U.S. Government Printing Office, 1967. 90 p. Commonly known as the "Charpie" report. HC110.T4A55.

Utterback, James M. Innovation in industry and the diffusion of technology. Science, v. 183, Feb. 15, 1974: 620-626. Q1.S35.

Vanishing innovation. Business week, July 3, 1978: 46-54. HF5001.B89.

Von Hippel, Eric. Appropriability of innovation benefit as a predictor of the functional locus of innovation. Cambridge, Mass., M.I.T. Sloan School of Management, 1979. (mimeo) 57 p.

———. The dominant role of users in the scientific instrument innovation process. Research policy, v. 5, July 1976: 212-239. Q180.A1R448.

Warner, Kenneth E. The need for some innovative concepts of innovation: an examination of research on the diffusion of innovations. Policy sciences, v. 5, Dec. 1974: 433-451. H1.P7.

THE RELATIONSHIP OF FEDERAL SUPPORT OF BASIC RESEARCH IN UNIVERSITIES TO INDUSTRIAL INNOVATION AND PRODUCTIVITY

By Mary Ellen Mogee*

CONTENTS

SUMMARY

This paper presents an overview of what is known about the relationship of federally supported basic research in universities to industrial innovation and productivity. It reviews evidence in three areas which bear upon this issue: the conceptual relationship between science and technology; the nature of university-industry relations; and economic studies of the contribution of research and development (R&D) to economic and productivity. The paper reveals that there is widespread agreement among university, government, and industrial officials that Federal support of basic research in universities is an effective method of enhancing the science base for industrial innovation. However, economic studies have been unable to isolate the precise quantitative contribution of basic research (as opposed to applied research and development) to economic growth and

*Analyst in Science and Technology, Science Policy Research Division, Congressional Research Service, Library of Congress.

productivity. The existence of institutional barriers between universities and industry may be obstructing the transfer of basic research results to industry, thereby preventing them from being embodied in new technology and contributing to improved economic productivity. The paper concludes that Federal funding of basic research in universities may be viewed as an investment that will have payoff primarily in improved efficiency of the R&D process and major technological changes that may permit continued improvements in economic productivity in the long-term future.

I. Introduction

This paper reviews what is known about the relationship of Federal support of basic research in universities to industrial innovation and productivity. Interest in this topic stems from growing concern about the state of industrial innovation and economic growth in the United States, witnessed, for example, by recent presidential Domestic Policy Review for Industrial Innovation. One of the primary issues is that of identifying appropriate and effective ways in which the Federal Government may act to stimulate innovation and productivity.

Direct support of research and development (R&D) and, in particular, basic research is a well-established area of Federal activity. The Budget of the United States Government, Fiscal Year 1980, stated the rationale for Federal support for basic research:

> The fundamental knowledge obtained through basic research improves man's understanding of natural laws and phenomena, of the environment on earth and in space, and of living things. The special role of universities and colleges in the conduct of basic research ensures a flow of trained scientists and engineers for the future. The results of basic research provide the foundation for applied research directed toward practical applications. Thus, basic knowledge is essential for the understanding and long-term solution of problems in many areas of national concern, such as economic growth, health, agriculture, energy environment, and national defense.[1]

Basic research performance in the United States is concentrated in the universities and colleges. In fiscal year 1978, about 60 percent of total national basic research was performed in universities, colleges, and associated federally funded R. & D. centers (FFRDCs). The Federal Government funded about 70 percent of total national basic research, and about 64 percent of Federal funding for basic research went to universities, colleges, and associated FFRDCs.[2]

Although there is widespread belief among university, government, and industry officials that Federal support of basic research in universities is an effective method of enhancing the science base for innovation in industry (which in turn contributes to improved productivity), there is very little empirical evidence that bears directly on the topic. Therefore, this paper reviews and synthesizes diverse evidence relevant to selected aspects of the topic.

The implicit model used in this paper is the following:

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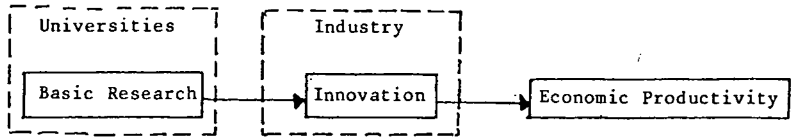
[1] U.S. Office of Management and Budget. "The Budget of the United States Government, Fiscal Year 1980." Washington. U.S. Government Printing Office, 1979, pp. 117–118.

[2] U.S. National Science Foundation. National Patterns of R. & D. Resources, Funds and Personnel in the United States, 1953—1978–79. Washington, U.S. Government Printing Office, 1978. (NSF–313), p. 4.



A word of caution with respect to models of the innovation process is in order. Many models of the process of technological innovation and its contributions to economic productivity have been suggested.[3] These models often postulate a linear progression from basic research, development, manufacturing and marketing start-up, to sales, and economic growth. The first annual Science and Technology Report described the process in the following terms:

> Research advances scientific knowledge, which, in turn, enhances the intellectual skills individuals bring to their work and provides a source of ideas for innovative technologies. These technologies lead to new and improved products, services and production processes. They in turn contribute to a more satisfactory life style and enhance the working skills of individuals.[4]

These models are admittedly oversimplified; in real life the progress of an innovation is never that straightforward. Somtimes stages are shortened, skipped, or overlapped. Sometimes a retreat must be made to more fundamental work. The activities may occur in different organizations or different countries, involve different persons, and long periods of time may elapse between activities. There are frequently multiple paths of activity leading to an innovation. This adds up to a complex and uncertain process about which we can make few generalizations at aggregate levels.

As primitive as they may be, however, such models provide some conceptual guidelines for investigation of important areas. Hence, the next three sections of this paper will examine evidence relevant to the following relationships: (1) The relationship between basic research and industrial innovation; (2) the relationship between industrial innovation and economic productivity; and (3) the relationships between universities and industry.

II. The Relationship of Basic Research to Industrial Innovation

This section of the paper examines evidence relevant to the relationship of basic research to industrial innovation, the primary path by which basic research may influence economic productivity. It discusses the differences between science and technology and the two main modes of transfer of basic research results to industrial innovation: (1) The transfer of scientific information through publications, reports, and other channels, and (2) the education of scientists and engineers.

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[3] Industrial innovation responds to at least three kinds of factors—economic, scientific/technological, and institutional. This paper concentrates on the scientific/technological factors, specifically on basic scientific research, but it should be recognized that the influence of these factors is always conditioned by the economic and institutional context. For instance, as will be discussed later, the contribution of basic research to technological innovation may be more direct and immediate when there is a demand for the innovation and there are few institutional barriers to the transfer of scientific information.

[4] U.S. National Science Foundation. Science and Technology: Annual Report to the Congress. Reprinted by the House Committee on Science and Technology. 95th Congress, 2d session. Washington, U.S. Government Printing Office, 1978, p. 58.

A. Differences Between Science and Technology

Basic research may be regarded as a process that contributes to the process of industrial innovation, culminating in the introduction of new and improved commercial products and processes. Basic research produces scientific knowledge aimed at *understanding* natural phenomena, while industrial innovation is aimed at *applying* knowledge to problem-solving for commercial objectives. This distinction parallels that between science and technology. Science and technology may be viewed as the two ends of a spectrum of scientific activity. Economist Richard Nelsen commented upon the differences between the basic and applied ends of this spectrum:

Moving from the applied-science end of the spectrum to the basic-science end, the degree of uncertainty about the results of specific research projects increases, and the goals become less clearly defined and less closely tied to the solution of a specific practical problem or the creation of a practical object. The loose defining of goals at the basic research end of the spectrum is a very rational adaptation to the great uncertainties involved and permits a greater expected payoff from the research dollar than would be possible if goals were more closely defined. For commonly, not just sometimes, in the course of a research project unexpected possibilities not closely related to the original objectives appear, and concurrently it may become clear that the original objectives are unobtainable or will be far more difficult to achieve than originally expected. While the direction of an applied research project must be closely constrained by the practical problem which must be solved, the direction of a basic research project may change markedly, opportunistically, as research proceeds and new possibilities appear. Some of the most striking scientific breakthroughs have resulted from research projects started with quite different ends in mind.[5]

Nelson and others have argued that basic research is more likely than applied research to result in significant breakthroughs in scientific knowledge because it is less concerned with practical problems.[6] Evidence to support this view, however, is inconclusive. On the other hand, basic research has some qualities that make it less desirable as an investment for industry than applied research. Significant advances in scientific knowledge often are of value in a wide range of fields, but a specific industrial firm may be unable to benefit from the results of basic research unrelated to its underlying technologies. Moreover, scientific knowledge is difficult to keep secret or protect, so competitors may benefit from it as much as the originator. Further, significant advances in scientific knowledge aften are not directly and immediately applicable to the solution of practical problems.[7]

Basic research may be viewed as contributing to a pool of scientific knowledge which may be drawn upon by all for different purposes. However, because the benefits may not be appropriable, there is little incentive for commercial firms to finance basic research. "Indeed," Nelson concluded, "there is a basic contradiction between the conditions necessary for efficient basic research—few or no constraints on the direction of research with full and free dissemination of research results—and full appropriation of the gains from sponsoring basic research in a competitve economy." [8]

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[5] Nelson, Richard. The Simple Economics of Basic Scientific Research. In Rosenberg, Nathan (ed.) The Economics of Technological Change. Baltimore, Penguin Books, 1971. pp. 153–154. Reprinted from Journal of Political Economy, v. 67, June 1959: 297–306.
[6] Ibid., p. 154.
[7] Ibid., pp. 155–156.
[8] Ibid., pp. 160–161.

Basic scientific research has another side to its character which removes it even further from the concerns of technology and industrial innovation. That is the aspect of scientific research which is regarded primarily as a cultural activity, rather than an activity oriented toward something commercially useful. It may be argued that some of the motivations of scientists are similar to those of artists and other humanists, and that one of the bases for societal support of science is that it is one of man's higher cultural activities. For this reason, as well as the ones enumerated above, the characteristics of basic research, make it more consistent with the objectives of institutions of higher learning—the production and transmission of knowledge—than with the objectives of industry—the production of goods and services for profit.

B. Studies of the Relationship Between Science and Technology

It is frequently claimed that the rate and character of scientific advances have significantly affected the rate and character of technological advances, especially in recent times. This is said to be particularly so for major advances in technology, as opposed to minor improvements.[9] Specific cases have been cited where basic research has led to major technological advances, such as transistors, nylon, dacron, hybrid corn, and radar.

In some cases the lack of scientific knowledge has held up the invention and introduction of important products. Nelson, Peck, and Kalachek argued that:

> . . . there was strong demand for products such as antiseptics and the telephone long before their invention. Had they been invented years before, there is little doubt that they would have been profitable. In both cases there is no question but practical experience played a role in posing the problem and in suggesting certain aspects of the solution. But in each, an essential part of the thinking which triggered the efforts at invention and was applied to solve the problem involved scientific understanding which did not exist before, the germ theory of infection in one case, the theory of electromagnetism in the other.[10]

In the 20th century whole industries based on science have grown up, such as the chemical, electronics, and aviation industries. It is argued that science is necessary to provide the basis for new industries of the future which will replace older industries of lower productivity. Science is sometimes pictured as the "engine" of technology, without which technological progress would eventually slow down and stagnate.

Nelson, Peck, and Kalachek argued that major technological advances come more easily in the science-based industries because of the large and continuing effort they put into basic and exploratory research.[11] Hamberg expressed the opinion that when an industry draws upon a well-developed basic science, R&D costs are lower.[12]

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[9] Mansfield, Edwin. The Economics of Technological Change. New York, Wiley, 1968, pp. 11–12.

[10] Nelson, Richard, Merton Peck, and Edward Kalachek. Technology, Economic Growth, and Public Policy. Washington, The Brookings Institution, 1967, p. 39.

[11] Ibid., p. 43.

[12] Hamberg, Daniel. Invention in the Industrial Laboratory. Journal of Political Economy, v. 71, April 1963: 95–115.

Nelson explained why this should be so:

In the activity of invention, as in most goal-directed activities, the actor has a number of alternative paths among which he must choose. The greater his knowledge of the relevant fields, the more likely he will be eventually to find a satisfactory path, and the fewer the expected number of tried alternatives before a satisfactory one is found. Thus, the greater the underlying knowledge, the lower the expected cost of making any particular invention.[13]

It is widely believed by students and practitioners of science and technology that improved scientific knowledge helps narrow the range of technological possibilities that must be explored to achieve a development, thus increasing the efficiency of the innovation process, but, again, the evidence is inconclusive.

Although the emphasis of this paper is on the contribution of science to technology, it should be remembered that the relationship between science and technology is not necessarily a simple or linear one of causation. For example, the attempt to understand the principles of performance of the steam engine gave rise to the discovery of the laws of thermodynamics. Technology may stimulate science through the provision of new materials, instruments, and problems for study. Moreover, technology is to a considerable extent self-contained in the sense that it builds on a body of engineering or production knowledge.

1. TRANSFER OF BASIC RESEARCH RESULTS THROUGH COMMUNICATION

Since the middle 1960's there have been several studies of the transfer of basic research results through channels such as oral and written communications. In 1965, based on an examination of citations in scientific and technological journals, Price concluded that science and technology progressed largely independent of one another.[14] Project Hindsight, sponsored by the Department of Defense, found basic science inputs to be of little importance to technological developments.[15] However, this may have been due to the short time period studied. Two other studies—TRACES and Interactions of Science and Technology in the Innovative Process—found basic research to be crucial to the innovations studied.[16] TRACES found that, on average, 30 years elapsed between basic research events and their technological application. A 1974 study by Gibbons and Johnston found that, of 900 knowledge inputs to 30 innovations, more than one-third of those inputs from outside the firm were from the scientific literature.[17] That study concluded that basic scientific research contributed to industrial innovation, both directly—through the transfer of information relevant to specific innovations via scientific literature or contact with basic

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[13] Nelson, op. cit., p. 152.

[14] Price, D. J. DeSolla. Is Technology Independent of Science? Technology and Culture, v. 6, 1965: 553–568. Cited in Thomas J. Allen, Managing the Flow of Technology, Cambridge, Mass., MIT Press, 1977, p. 51.

[15] Isenson, Raymond S. Project Hindsight. Final Report. Report to the Office of the Director of Defense Research and Engineering, 1969. National Technical Information Service, mimeo.

[16] Illinois Institute of Technology Research Institute. Technology in Retrospect and Critical Events in Science. Prepared for the National Science Foundation under contract NSF–C535, 1968. And Battelle-Columbus Laboratories. Interactions of Science and Technology in the Innovative Process. Final Report. Prepared for the National Science Foundation under contract NSF–C667, 1973.

[17] Gibbons, Michael, and Ron Johnston. The Role of Science in Technological Innovation. Research Policy, v. 3, 1974: 237–238.

research scientists—and indirectly, through the education and maintenance of expertise of industrial engineers.

A recent study of citation patterns in patent applications for prostaglandins and gas lasers found strong ties to the scientific literature.[18] Eighty percent of the references from prostaglandin patents to all sources (patents, scientific journal articles, and miscellaneous sources) were to papers in scientific journals and about one-third of the references in gas laser patents were to scientific journals.[19] Moreover, the scientific literature cited was relatively recent:

> The median age of the cited papers from the prostaglandin patents was about six years, two years older than the median age for papers cited by typical chemical papers. The gas laser patents cited literature with a median age of only three years, two years younger than the median age of papers cited by typical physics papers.[20]

Innovation researcher Thomas Allen has suggested that a long time lapse ordinarily occurs between a scientific advance and a technological advance that utilizes it. This delay however, may be significantly shortened under certain conditions—specifically, when a technology has advanced to a limit at which an improved understanding of the basic science involved is required; when the problem is communicated by technologists to basic scientists in terms of a basic research problem; when the scientists attack and resolve the problem; and when the solution is passed back into the technology immediately. Thus direct and immediate application of basic research to technology seems to occur when the technological problem is the driving force and can be translated into an interesting and researchable basic science problem.[21]

2. TRANSFER THROUGH EDUCATION OF SCIENTISTS AND ENGINEERS

Many students of innovation believe that a large part of the effect of basic research upon industrial innovation is made through the education of industrial scientists and engineers.[22] Much of the flow of scientific and technical information into the industrial firm is "person-embodied." It has been found that the communication of a teacher to students and the movement of graduates into industry are among the most effective channels of information transfer.[23]

Gibbons and Johnston, writing about Europe where there are distinct educational programs oriented either towards industry or academia, found that the type of education which predominates in an industry partly determines the types of innovations undertaken. Those with predominantly industry-oriented education are limited to seeking solutions to problems that lie within their educational training or industrial experience, while those with predominantly academic training have the ability to try a wider range of solutions.[24]

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[18] Carpenter, Marp P., and Francis Narin. Utilization of Scientific Literature by U.S. Patents. Cherry Hill, N.J., Computer Horizons, Inc., 1978. 62 p. Prepared for the National Science Foundation under contract NSF PRM-7801694.
[19] Ibid., p. 30.
[20] Ibid., p. iv.
[21] Allen, op. cit., pp. 52–53.
[22] Haeffner, Erik. The Innovation Process. Technology Review, v. 75, March/April 1973.
[23] Shimshoni, D. Aspects of Scientific Entrepreneurship. (Thesis) Cambridge, Mass., Harvard University, 1966.
[24] Gibbons and Johnston, op. cit., pp. 237–238.

C. Summary

Basic research, because of its remoteness from commercial objectives and the difficulty of appropriating its benefits, is not an attractive investment for industry, but it is well-suited to the academic environment. Thus, Federal support for basic research in universities appears to take advantage of the natural capabilities of the universities and provides funding where there is insufficient incentive for private sector funding.

The contribution of basic research to industrial innovation usually appears to be indirect and delayed, occurring largely through improving the information and education of industrial scientists and engineers. In cases where the contribution has been direct and immediate, it often has been stimulated by the existence of an urgent technological problem requiring improved scientific understanding. Moreover, the contribution may be more direct in cases where an industrial technology is closely related to a scientific discipline, such as in the chemical or electronics industries.

Although the contribution is usually indirect and delayed, science seems to act as an "engine" of technology, without which specific innovations may be delayed or prevented and technological progress may eventually stagnate. Basic research seems to reduce the cost of later stages of R&D and innovation by providing improved knowledge of the likely paths for development.

III. The Relationship of Industrial Innovation to Productivity

This section reviews evidence relevant to the relationship of industrial innovation to economic productivity, which is a measure of the efficiency of economic production systems. Industrial innovation results in new and improved products and production processes which improve productivity by increasing the amount of output per unit input.

A. Research and Development and Economic Growth and Productivity

While new products and processes may result from sources other than organized R&D (such as independent inventors and on-the-line improvements), R&D is aimed specifically at developing new products and processes, and data on R&D inputs are available. For these reasons, most studies of the relationship of industrial innovation to productivity have used R&D data.

Research and development activity is commonly defined to include the activities of basic research, applied research, and development. To the extent that basic research is included in R&D, the subject studies are relevant to the question of the contribution of basic research to productivity growth. However, R&D represents a spectrum of activity in which basic research is at the most uncertain and least directed end, and development is at the less uncertain and more directed toward commercial objectives end. Thus, it is to be expected that applied research and development will be more closely related to economic growth and productivity improvement than will be basic research. In fact, most economic studies include only data on applied research and development, because industry does little basic research.

Economic studies of the relationship between R&D and economic growth and productivity have been made at the level of the individual innovation, the firm, the industry, the economic sector, and the national economy.[25] In general they have attempted to: (1) Determine the existence of statistical correlations between patterns of R&D expenditures and patterns of economic growth and productivity improvement over time, or (2) calculate rates of return on investment in R&D. It should be noted that statistical correlations do not prove that cause-and-effect relationships exist; they merely show similarities in patterns. Nonetheless, the existence of strong correlations reinforces theory. The findings of many studies suggest that there is a significant relationship between R&D expenditures and economic growth and productivity.

Most studies at the firm level use total expenditures on R&D as a measure of R&D resources; this is generally expressed as a ratio of R&D to total sales, or total current expenditures, and data are collected over a number of years to minimize year-to-year variability. Data collected by the National Science Foundation are the primary source, although more detailed data are being developed by some researchers.

The measure of "economic growth" at the firm or industrial level is usually growth of sales or profits; at the national level it is increase in the gross national product (GNP). This is a measure of the growth of the Nation's economic output. Of more interest is the change in economic productivity (output per unit input), which is a measure of the efficiency with which inputs are converted into useful goods and services. Inputs include labor, raw materials, capital (largely plant and equipment), and common resources (e.g., air and water). However, data on inputs other than labor are not generally available on a disaggregated industry basis, so labor productivity (output per person-hour) is used instead of total factor productivity.

1. MEASUREMENT AND METHODOLOGICAL PROBLEMS

There are many problems associated with the measurement of economic output and productivity, particularly with the valuation of inputs and outputs. Some of those that pertain specifically to R&D will be discussed here.

The national income accounting method and other methods of accounting for economic outputs have difficulty in dealing with qualitative changes in outputs, as opposed to quantitative increase in the production of the same products. A large qualitative change would be represented by a completely new product, such as the television when

[25] This section draws heavily from the following National Science Foundation colloquia: U.S. National Science Foundation. Research and Development and Economic Growth/Productivity. Papers and Proceedings of a Colloquium. Washington, U.S. Government Printing Office, 1972. (NSF 72–303); and U.S. National Science Foundation. Relationships Between R&D and Eocnomic Growth/Productivity. Preliminary Papers for a Colloquium. Draft, Nov. 9, 1977. Participants at the first colloquium reviewed the literature existing to that date. Participants at the second colloquium reviewed the literature appearing in the interim. Findings of the second colloquium tended to confirm the earlier ones.

it was first introduced; a lesser change would be the introduction of color television. The greater the degree of qualitative change, the more difficult it is to account for it. This problem is particularly important in measuring the benefits of R&D because R&D often leads to qualitative chages in products and the introduction of new products. The first annual Science and Technology Report stated "there is good reason to believe that if qualitative factors were included, then the measured returns [to R&D] would be higher." [26]

Other outputs that are generally not adequately accounted for include environmental quality, consumer and worker health and safety, and possible harmful byproducts of new technology. This is because they are not considered to be economic outputs. As a consequence, the allocation of resources to achieve "noneconomic" objectives may result in slow economic growth according to the national accounting methods. Also, it should be noted that economic growth and productivity do not measure the benefits of national programs such as defense, energy, and space which account for a considerable proportion of R&D funds.

Another major problem with measures of economic growth and productivity is that many factors affect them. Among these are: technological change, improved labor skills and education, increases in capital intensity, improved organization of production, imported technology, or change in the social barriers to economic growth and efficiency. The relative influence of these factors is not known with accuracy. There are reasons to believe that many of them are highly interrelated, but the magnitude of the interrelations is not currently known. This complicates the task of isolating the influence of technological change.

Two general methods are used to determine the relationship between R&D and economic growth: direct econometric methods (generally at the level of the innovation, firm, or industry) and aggregate residual methods (at the level of the national economy). The impact of R&D on the economy cannot be understood fully by examining the relationship at the firm or industry level because much of the payoff takes the form of new or improved products which may raise productivity in the industries that use them as inputs. For instance, new chemical products have been a major source of productivity improvement in the textile industry. Thus, it is not possible to determine the impact of R&D on the national economy by simply summing studies of firms and industries.

The process of measuring the contribution of R&D to economic growth and productivity at the national level is one of elimination. The growth which is attributable to increases in factor inputs, such as labor and capital, is subtracted from that total. The residual (that part of increase in output not attributable to increased factor inputs) is then assumed to be the result of technological progress. "But in fact the residual is growth resulting from a variety of couses, known and unknown, measurable and unmeasured." [27] Only part of the residual growth may be due to organized R&D.

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[26] Science and Technology: Annual Report to the Congress, p. 62.

[27] Stewart, Charles T., Jr., A Summary of the State-of-the-Art on the Relationship Between R&D and Economic Growth/Productivity. In U.S. National Science Foundation Research and Development and Economic Growth/Productivity, op. cit., p. 14.

The 1971 NSF colloquium listed additional limitations, including: the difficulty of going from contributions of technological change to the specific contribution of R&D; the problem of estimating the time lag between R&D investment and economic impact; and the difficulty in deflating R&D expenditures for price changes.[28]

2. SUMMARY OF FINDINGS

The methodological problems described above can have a significant impact on the estimates one obtains. Two NSF colloquiums which addressed this issue (1971 and 1972) reported that little progress had been made in solving the basic measurement and modeling problems.[29]

Despite these problems, a review of the research literature on this subject revealed in 1971, and again in 1977, that most studies pointed in a common direction. The 1971 colloquium summarized the general understanding of the relationship between R&D and economic growth and productivity as follows:

> Although what we know about the relationship between R&D and economic growth/productivity is limited, all available evidence indicates that R&D is an important contributor to economic growth and productivity. Research to date seeking to measure this relationship (at the level of the firm, the industry, and the whole economy) points in a single direction—the contribution of R&D to economic growth/productivity is positive, significant and high.[30]

More recent studies, reviewed at the 1977 NSF colloquium, have extended the coverage to more firms, more industries, and more recent time periods. These studies tend to confirm the findings of the earlier research that the contribution of R&D to economic growth and productivity is high. The direct average gross rate of return on private R&D expenditures appears to be 30 to 40 percent.[31] While these returns are high compared to alternative investments, the total effect on the economy may be even greater due to the indirect benefits to users and consumers. Recent research shows that the returns to society at large substantially exceed the returns received by the firms performing the R&D; the social rate of return seems to be about twice the private rate of return.[32]

Stewart summarized the state of our knowledge at the aggregate level in 1971:

> . . . There is only one attempt to estimate the specific contribution of organized research, Denison, and that can be best described as a guesstimate. His revised judgment is that the advance of knowledge contributed about 0.76 percentage points to average annual productivity gain for the period 1929–1957, and the same for 1950–1962. This accounted for 42 percent of total annual average productivity gain for the longer period. Of this, however, Denison attributed only one-fifth, or 0.15 percentage points, to organized research conducted in the United States. This estimate is derived from three other estimates: (1) that about one-half of the contribution of the advance of knowledge to productivity growth is accounted for by technological progress, and one-half by managerial and or-

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[28] Lederman, Leonard L. Summary of the Papers. In U.S. National Science Foundation. Research and Development and Economic Growth/Productivity, op. cit., p. 5.

[29] Mansfield, Edwin. Contribution of Research and Development to Economic Growth of the United States. In U.S. National Science Foundation. Research and Development and Economic Growth/Productivity, op. cit., p. 25.

[30] U.S. National Science Foundation. Research and Development and Economic Growth/Productivity, op. cit., p. 3.

[31] Nadiri, M. Ishaq. The Contribution of Research and Development to Economic Growth. In NSF, Relations Between R. & D. and Economic Growth/Productivity (1977). p. B–23.

[32] Mansfield, Edwin, et al. Social and Private Rates of Return from Industrial Innovations. Quarterly Journal of Economics, v. 91, May 1977: 234.

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ganizational progress; (2) that no more than one-half the contribution of technological progress to productivity gains originate in the United States; and (3) that organized research, captured by R&D statistics, is not the sum total of productivity-relevant research conducted in the United States, but perhaps two-thirds of it.[33]

Denison has updated these findings through 1969; they indicate that about 50 percent of measurable U.S. economic growth between 1948 and 1969 derived from advances in knowledge.[34]

B. Federally Funded R&D

Recent studies suggest that the relationship between R&D and economic growth and productivity may differ by industry and by source of funding. In particular, increasing attention has been paid to the relative productivity-enhancing effects of privately- versus publicly-funded R&D. Results based on firm and industry data seem to suggest that the direct contribution of federally funded R&D to economic growth is negligible. Moreover, its indirect or spill-over effect does not appear to compare favorably with R&D funded by the private sector. The specificity of federally funded R&D and its concentration in a few defense or space-oriented industries are suggested as possible explanations.[35] An exception to this pattern of findings is a study by Chase Econometrics which reported high rates of return for public expenditure on space-related R&D.[36] A General Accounting Office report, however, concluded that the Chase study may have overestimated the returns.[37]

Finding that Federal R&D expenditures makes little or no contribution to productivity appear to be contrary to widely held views. In fact, examples can be cited of important innovations resulting from Federal R&D in electronics, aerospace, and atomic energy. A possible explanation for this apparent anomaly might be as follows: since most Federal R&D expenditures have been made to further Federal missions in such areas as space and defense, the resulting technology has not primarily been used in the production of economic goods and services, thus making little contribution to productivity. In a few selected areas, however, the technology has been transferred to the private sector and has made a significant economic impact. The findings should be regarded as preliminary at this time since they may be due to measurement or methodological problems, or to the high degree of concentration of Federal R&D funds in a few industries.

C. Basic Research and Productivity

Economic studies provide little empirical evidence about the contribution of basic research to productivity. Most studies at the industry

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[33] Steward, op. cit., pp. 16–17.
[34] Denison, Edward F. Accounting for United States Economic Growth, 1929–69. Washington, D.C., The Brookings Institution, 1974. p. 128. Cited in Science and Technology: Annual Report to the Congress, p. 58.
[35] Nadiri, M. Ishaq, and Nestor Terleckyj at the 1977 NSF colloquium on Relationships Between R&D and Economic Growth/Productivity.
[36] Evans, Michael K. The Economic Impact of NASA R&D Spending. Final Report. Chase Econometric Associates, Inc., Bala Cynwyd, Pa., prepared for the National Aeronautics and Space Administration under contract NASW–2741, 1976.
[37] U.S. General Accounting Office. NASA Report May Overstate the Economic Benefits of Research and Development Spending. Washington, 1977 (PAD–78–18).

or firm level have been limited to measures of applied research and development inputs, because very little basic research is conducted in industry. Studies at the aggregate level have not partitioned the contribution of organized research into its basic research, applied research, and development components. Moreover, the lagtime used in most studies is not long enough to capture the effects of basic research. The first annual Science and Technology Report stated:

> The value to society of basic research findings vis-a-vis applied research or development results simply cannot be assessed in terms that will allow us to say that basic research should have *x* dollars added to it or that *y* dollars should be taken away from another phase of the R&D process. Therefore, we cannot say whether or not an economy that devotes 9 percent of its R&D funds to basic research and 69 percent to development (as was true in 1960) is better or worse off than an economy that spent 13 percent of its R&D budget on basic research and 65 percent on development (the case in 1977).[38]

Given the uncertain nature of basic research, its distance from commercial objectives, and the long time to application, one would not expect to find a strong, direct relationship between basic research and productivity. Economists have posited two primary roles for basic research: improving productivity of the R&D process itself and improving national productivity in the long run. These will be discussed in turn.

Stewart argued that basic research raises the productivity of applied research and development by indicating fruitful paths of inquiry and paths that should be avoided, thereby reducing costly mistakes and wasted effort. Improved productivity in R&D is important to the extent that it permits more efficient use of R&D funds. However, this would show up as a very small contribution to productivity at the national level.[39] Moreover, the contribution of basic research to improved productivity in applied research and development has not yet been measured. Stewart commented:

> What you're really trying to do is to improve productivity of applied research by increasing the pool of basic knowledge. Since you can't measure the productivity of applied research very well, I doubt that you're ever going to be able to measure the contribution of basic research to raising the whole production function for applied research.[40]

Basic research also appears to play a role in improving productivity in the long run. Funds for applied research and development have a higher probability than basic research of contributing to improved productivity over the next five years, through embodiment in new or improved products and production processes. The productivity increases possible from improvements in any given technology will gradually decrease over time and approach a limit, however. Breakthroughs in scientific or technological understanding are often required to make quantum jumps in productivity.[41] Such breakthroughs frequently stem from basic research done 20 to 30 years previously. Long-term productivity improvements may therefore depend heavily on basic research funding today.

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[38] Science and Technology: Annual Report to the Congress, p. 96.
[39] Lederman, Leonard. Comment in Research and Development and Economic Growth/Productivity, p. 69.
[40] Stewart, op. cit., p. 67.
[41] See, for example, Hollander, Samuel. The Sources of Increased Efficiency. Cambridge, MIT Press, 1965; and Abernathy, William and James Utterback. Patterns of Industrial Innovation. Technology Review, v. 80, June/July 1978. 41–48.

A recent paper by Mansfield reports the results of what is believed to be the first econometric study of the relation between basic research and productivity at the level of firms and industries.[42] Those results indicate a statistically significant and direct relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, when its expenditures on applied R&D are held constant. This study is preliminary and based on data for 1958, so the results must be regarded as tentative. Nonetheless, they appear to be at odds with theoretical expectations about the productivity-enhancing potential of basic research. It should be emphasized that this study referred to basic research performed by industry, not by universities. Basic research conducted by industry may have more productivity-enhancing potential than that performed in universities—if there is a tendency for the performing firm or industry to exploit its own basic research more fully or if applied research and development are more effective when carried out in conjunction with basic research.

D. Summary

Despite methodological problems, economic studies point in a common direction: The contribution of R&D to economic growth and productivity is high, the return to private investment in R&D is high compared to alternative investments, and the return to society-at-large is about twice the private return. However, these findings are based primarily on data for applied research and development and, therefore, may not apply to basic research. The chief role of basic research may be its contribution to improved efficiency (productivity) of the R&D process itself, and its contribution to major technological changes that will permit significant increases in national productivity in the long-term future. Preliminary evidence indicates that basic research performed in industry may directly affect its productivity growth.

Preliminary evidence suggests that the payoff to federally-supported R&D in the near term may be low or negligible. Again, such findings are based on data for applied research and development, but they could be significant for Federal support of basic research. These findings, however, should be regarded with caution until they are further confirmed or explained. It is possible that the apparently low payoff is a function of concentration of Federal R&D in space and defense industries.

IV. The Relationships Between Universities and Industry

This section of the paper reviews evidence on relationships between universities and industry as they affect the transfer of basic research results to practical applications.

A. Universities as Centers for Basic Research

A large portion of the basic research in the United States is performed in institutions of higher education (60 percent in fiscal year

[42] Mansfield, Edwin. Basic Research and Productivity Increase in Manufacturing. Philadelphia, University of Pennsylvania (mimeo), n.d.

1978).[43] Bush in 1945 described some prevailing beliefs about the role of universities in research and innovation. He stated:

The publicly and privately supported colleges, universities, and research institutes are the centers of basic research. They are the wellsprings of knowledge and understanding. As long as they are vigorous and healthy and their scientists are free to pursue the truth wherever it may lead, there will be a flow of new scientific knowledge to those who can apply it to practical problems in Government, in industry, or elsewhere.

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Publicly and privately suported colleges and universities and the endowed research institutes must furnish both the new scientific knowledge and the trained research workers. These institutions are uniquely qualified by tradition and by their special characteristics to carry on basic research. They are charged with the responsibility of conserving the knowledge accumulated by the past, imparting that knowledge to students, and contributing new knowledge of all kinds. It is chiefly in these institutions that scientists may work in an atmosphere which is relatively free from the adverse pressure of convention, prejudice, or commercial necessity. At their best they provide the scientific worker with a strong sense of solidarity and security as well as a substantial degree of personal intellectual freedom. All of these factors are of great importance in the development of new knowledge, since much of new knowledge is certain to arouse opposition because of its tendency to challenge current beliefs or practice.

Industry is generally inhibited by preconceived goals, by its own clearly defined standards, and by the constant pressure of commercial necessity. Satisfactory progress in basic science seldom occurs under conditions prevailing in the normal industrial laboratory. There are some notable exceptions, it is true, but even in such cases it is rarely possible to match the universities in respect to the freedom which is so important to scientific discovery.[44]

The idea that the best basic research is done in universities rather than industry is widely held, but the evidence is inconclusive. Although there are a small number of outstanding industrial laboratories where high-quality basic research is performed, including: Bell Labs, General Electric, Hughes Aircraft, Dupont, and IBM. Moreover, it may be argued that the best basic research in universities is likewise concentrated in a small number of top institutions.

A recent report for the National Science Foundation, which surveyed industrial firms with respect to industry-university interactions in basic research, found a general perception that the universities should be the principal location for basic research.[45]

B. University-Industry Interaction

Industry and universities have traditionally established ties through inter alia, graduating students, the industrial use of academic consultants, and technical society activities. An article in Chemical Week described basic research contracts between such firms as Monsanto, Dow Chemical, and W.R. Grace, and universities.[46]

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[43] U.S. National Science Foundation. National Patterns of R&D Resources, Funds and Personnel in the United States, 1953—1978–79. Washington, U.S. Government Printing Office, 1978. (NSF 78–313) p. 4.

[44] Bush, Vannevar. Science: The Endless Frontier. July 1945. Reprinted by the National Science Foundation. Washington, D.C., July 1960, pp. 12, 19.

[45] Nason, Howard K., and Joseph A. Steger. Support of Basic Research by Industry. Report prepared for the National Science Foundation, Division of Science Resources Studies. Grant NSF–C76–21517, 1978, pp. 41–42.

[46] Industry R&D Renews the Old Campus Ties. Chemical Week, v. 124, Feb. 21, 1979: 38.

Representatives of industry acknowledge the importance to industry of the universities as sources of trained personnel and ideas for technological developments. Fusfeld wrote:

It is well known, of course, that in the physical sciences, the technical community is critically dependent on the university for its fundamental mission of education, and its conduct of basic research, which makes the educational process most effective and provides for the optimum contribution from the faculty. In addition, there are the highly-valued, but ill-defined, functions of simply expanding our reservoir of basic knowledge and contributing to the advancement of society.[47]

A similar view has been expressed by Fakstorp and Idorn:

More than any other operational function in industry, R&D was and is aware of its dependence on the academic institutions in their dual role as providers of trained scientists, engineers, and scholars with advanced degrees, and also as providers of important research results, representing advances of knowledge and of general scientific methods and insights. These results of academic research represent, of course, important and sometimes crucial inputs for industrial innovation.[48]

A group of industry consultants to the National Science Foundation in 1976 advised that NSF funding of basic research in universities was crucial to the health of industry and the Nation.[49]

Table 1, below, from the first annual Science and Technology Report, shows that since 1960 the proportion of industrial R&D funds for basic research has decreased from eight percent to four percent. The decline in industrial basic research funding has recently been a source of concern in policy circles. The causes for this decline are critical to any proposed Government action and may bear on the utility of university basic research to industry. The following explanations have been offered for the decline:

(1) The expansion of industrial R&D in the 1950's and 1960's showed management that basic research does not pay;

(2) Innovation came to be perceived as a "wet noodle"—easier to pull with market demand than to push with new science and technology;

(3) Past innovations led to current needs for technical improvements as opposed to further major advances;

(4) Erosion of corporate profitability has cut into discretionary expenditures such as basic research;

(5) Government regulations and policies have diverted industrial R&D from long-term to short-term objectives; and

(6) The energy crisis has diverted much industrial R&D.[50]

There is probably some truth to each of these statements but their relative importance has not been established.

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[47] Fusfeld, Herbert I. New Approaches to Support and Working Relationships. Research Management, v. 19, May 1976: 21.

[48] Fakstorp, Jorgan, and G. M. Idorn. University-Industry Relations in Europe. Research Management, July 1978, v. 21: 34.

[49] U.S. National Science Foundation. A Report on Research In Industry: Roles of the Government and the National Science Foundation. Washington, 1976. Attachment A. "NSF-Industry Task Force Preliminary Report" (NSB-76-348, revised). pp. 3-4.

[50] Healey, Frank H. Industry's Needs for Basic Research. Research Management, v. 21, November 1978: 15-16; and Manners, George E., Jr., and Howard K. Nason. The Decline in Industrial Research—Causes and Cures. Research Management, v. 21, September 1978: 8-11.

TABLE 1.—ALLOCATIONS OF INDUSTRY R. & D. FUNDS

[Dollar amounts in millions]

	Total R. & D.	Basic	Basic percent of total
1960	4,516	342	8
1961	4,757	361	8
1962	5,123	394	8
1963	5,456	425	8
1964	5,888	434	7
1965	6,548	461	7
1966	7,328	510	7
1967	8,142	492	6
1968	9,005	535	6
1969	10,010	540	5
1970	10,439	528	5
1971	10,813	547	5
1972	11,688	555	5
1973	13,258	597	5
1974	14,824	641	4
1975	15,747	686	4
1976	17,666	742	4
1977 (estimate)	19,408	783	4
1978 (estimate)	21,475	840	4

Source: U.S. National Science Foundation, National Patterns of R. & D. Resources, 1953—1978-79. Washington, 1978. (NSF 78-313). Excerpted from first annual Science and Technology Report.

The importance of university research to industry may be reflected in R&D statistics. Table 2 shows that industrial funding for basic research at universities and colleges has increased from seven percent of industrial basic research funding in 1960 to 10 percent in 1977. Industry funding, however, accounts for only about three percent of all support of scientific activities in universities and colleges, down from 11 percent in 1953.[51]

TABLE 2.—*Percent of industrial basic research funding transferred to universities*

	Percent
1960	7
1961	7
1962	6
1963	6
1964	6
1965	6
1966	5
1967	6
1968	7
1969	7
1970	8
1971	8
1972	10
1973	10
1974	10
1975	10
1976	9
1977 (preliminary)	10
1978 (established)	9

Source: U.S. National Science Foundation. National Patterns of R. & D. Resources, Funds and Personnel in the United States 1953—1978-79. Washington, 1978. (NSF-78-313). Tables B-2, B-6.

[51] Nason and Steger, op. cit., p. 42.

A report by the Organization for Economic Cooperation and Development (OECD) has pointed out that aggregate-level statistics on industrial funding for university research may not reveal the true extent of the interaction. It stated:

A closer look reveals that in many industrialized OECD countries, industry contributes considerably—not to the financing of the national university system, but to the financing of selected university departments, chairs, and research institutions. Cases of open financial support for clearly defined university purposes have been reported from the big science-based companies of many countries, for example, the Netherlands, Germany, Italy, Switzerland, the United States.[52]

The first annual Science and Technology Report concluded:

The shifting mix of research performers suggests that both industry and government believe that universities have comparative advantage in performing basic research. This raises the issue of knowledge transfer mechanisms. Industry apparently believes that some effective transfer is possible and that researchers in other sectors are prepared to deal with industry's interests in eventual economic payoff.[53]

C. Industrial Use of University Research

This section reviews findings on the use of university research by industry. Project Hindsight found that only nine percent of the R&D events leading to the technological developments studied took place in universities. This may have been due to the very short period prior to the developments studied. The TRACES study, which pursued events much further into the past, found that 60 percent of the R&D events took place in universities.

Three studies of innovation undertaken in the United Kingdom found that the primary sources of information inputs to industrial innovation from outside the firm were other industrial firms, government-funded technological institutes, and universities. The proportion of knowledge from outside sources coming from universities varied from 11 to 28 percent. Pavitt and Walker, who reviewed these studies, concluded: ". . . Government-funded R&D outside industry appears to provide an essential scientific and technological infrastructure which is used by industry." [54]

A recent study by Allen of the use of literature by engineers found that of formal publications (e.g., books, journals, periodicals), textbooks were the most frequently used. There was little use of scientific journals, or even professional engineering journals. The use of informal literature sources (primarily unpublished reports) was found to be more important, but there was hardly any use of university reports. Allen hypothesized that the lack of use:

. . . may well result from the fact that little of the work done in engineering schools is of any direct relevance to industry. In addition, university reports . . . are written for a very limited audience and cannot be understood by most engineers.[55]

Allen concluded that reliance on textbooks and the low use of university reports indicated that industrial engineers rely little upon current university research.[56]

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[52] OECD. The Conditions for Success in Technological Innovation. Paris, 1971, p. 93.
[53] Science and Technology: Annual Report to the Congress, p. 99.
[54] K. Pavitt and W. Walker, op. cit. p. 22.
[55] Allen, op. cit., pp. 71–73, 89–90.
[56] Ibid., p. 90.

The Computer Horizons study of patent citations found that the papers cited in prostaglandin patents were mainly authored by scientists from the following sectors, in order of importance: universities (38 percent), foreign (29 percent), and private industry (26 percent). The pattern in gas laser patents was different: private industry (46 percent), foreign (25 percent), and universities (12 percent). The authors commented that a smaller proportion of the citations from these patents were for work performed at universities than one would expect, given the overall contribution of universities to the cited fields. No data were presented to support this, however.[57]

The intensity of the use of university research by industry probably varies considerably by academic discipline and industrial sectors. For example, university research in chemistry may play a more important role in industrial innovation than physics, although this remains to be investigated.[58] A 1970 report of university-industry relations in the United Kingdom found that high technology industries have the highest proportion of qualified scientists and engineers in senior management, have the most contacts with universities, and make the most use of university consultants. That study also found that university departments' contacts with industry tended to be more frequent in pharmacology, chemistry, and physics than in biological science, biochemistry, and mathematics. Marquis and Allen found a greater dependence on science in nuclear engineering, electronics, and metallurgical engineering, by comparison with mechanical engineering.[59]

An OECD report stated:

> Where the links between university science and industrial technology are strong, the mere imitation of already known, but sophisticated, technologies has become so difficult that it requires scientists of no less calibre than those who were necessary to invent the technologies the first time. In such sectors, the possibilities of developing new technologies without fundamental science cannot be great either.[60]

Moreover, the OECD report argued:

> . . . an effective interface [between universities and industry] is no doubt created by the existence, on the one hand, of "fundamental" research in industry, which looks not only into the firm towards application, but also towards the universities and standards of academic excellence; and, on the other hand, of "applied" research in the universities which attains standards of academic excellence but which also looks towards application.[61]

It went on to suggest that:

> The key component in the industry/university interface is the recognition by industry of the potential contribution of fundamental science to industrial innovation, rather than the performance of "applied" research in the universities.[62]

D. Possible Barriers to University-Industry Interaction

Although universities may provide the most congenial environment for basic research, the results must be transferred to industry in order to be embodied in new and improved products and services, and thus contribute to improved productivity. Nevertheless, there are impor-

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[57] Computer Horizons, Inc., op. cit., pp. 42, 44.
[58] OECD, op. cit., p. 85.
[59] Ibid., p. 86.
[60] Ibid.
[61] Ibid., p. 95–96.
[62] Ibid., p. 96.

tant differences between universities and industry with respect to patents, publications, and freedom of research direction that may hinder the transfer of research results.[63]

While these problems are substantial, solutions have been found in the past. For example in 1977 Monsanto Company agreed to give Harvard Medical School $23 million in research support and endowment money over a period of 12 years for research on a biological substance that may be related to cancer. In return, Monsanto receives the patent rights, if any arise. According to Harvard, the principal investigators are involved in "basic cell research." [64] A Monsanto official has stated that although the short-range objectives of the two institutions may differ, they have similar long-range objectives. Monsanto's objective was to obtain a better understanding of biology (Monsanto's own strengths are in chemistry) as a foundation for possible business ventures in areas such as food, health, and energy.[65]

Other examples of university-industry cooperative efforts include arrangements between General Tire and Rubber with the polymers group at the University of Massachusetts, General Electric Research and Development Center's Visiting Scientist Program, and the Laboratory for Laser Energetics at the University of Rochester, which is supported in part by funds from Exxon and General Electric.[66] There are probably many more examples, but no comprehensive catalog of university-industry cooperative activities exists.

The Chemical Week article expressed the opinion that universities and industry have grown further apart in their basic research relationships over the past 25 years.[67] Herbert Doan, formerly of Dow Chemical, has suggested that this may have been due to the great increase in funding for basic research in the universities after World War II.[68] There are, however, no data on the overall level and nature of university-industry interactions, so such suggestions are necessarily impressionistic.

In any event, concern has been expressed by the scientific and technological communities that more effective communication and cooperation between scientists in institutions of higher education and those in industry, are needed. The first annual Science and Technology Report recommended continuing examination of the need to enhance "the linkage between the performers of research, in particular between industry and universities." It continued:

> . . . Most of the basic research in the United States is performed in a university setting, whereas the development effort is largely an industrial activity. If the desired flow of information is to occur, as well as the highly valuable cross fertilization, it is important that industry-university relationships be strengthener and that technology transfer mechanisms be improved.[69]

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[63] Chemical Week, op. cit., passim.

[64] Culliton, Barbara J. Harvard and Monsanto: The $23-Million Alliance. Science, v. 195, 25 February 1977: 759.

[65] Throdal, M. C. Presentation at Engineering Foundation Conference on Engineering and Science Research for Industrial Development. Easton, Md., October 3–7, 1977.

[66] Cooper, Martin J. Universities and the Private Sector—Opportunities for Mutual Gain in the Decade Ahead. Journal of the Society of Research Administrators, v. 10, Winter 1979: 28.

[67] Chemical Week, op. cit., p. 38.

[68] Doan, Herbert D. New Arrangements for Industry-Academic Research. Research Management, v. 21, March 1978: 33.

[69] Science and Technology: Annual Report to the Congress, pp. 6–7.

The 1976 group of industrial consultants to the National Science Foundation noted that insufficient interaction exists among industry, the universities, and government in the area of basic research.[70] Similarly, the 1978 report for NSF on basic research support in industry found that "not much" interaction occurs between industry and universities in basic research, either in terms of actual dollar support or joint effort.[71] Pavitt and Walker concluded from a study of government policies for innovation that their influence in strengthening the university-industry linkage has been "very limited." They said: "These links, which . . . are of critical importance to technological innovation, are made through autonomous initiatives between the two types of institution." [72]

Suggestions have been made that government should attempt to encourage such interaction. Such suggestions were made in the course of the recent Presidential Domestic Policy Review on Industrial Innovation.[73]

In the 96th Congress, bills have been introduced on the same subject. S. 1065, Tax Credit on Corporate Gifts for Basic Research, would amend the Internal Revenue Code of 1954 to allow a 25 percent tax credit for corporate contributions to educational institutions for basic scientific research. S. 1250, the National Technology Innovation Act of 1979, would create Centers for Industrial Technology at universities or other nonprofit institutions for the purpose of cooperative technological innovation activities with industry, including the development of the generic research base underlying an industry.

While there may be a good deal of support in the R&D community for measures to stimulate the interaction of universities and industry in innovation activities, certain reservations should be noted. Critics have pointed out that current problems of capital formation and government regulation make it difficult for industry to construct new plant and modernize equipment, thus reducing its incentive to finance the development of new technology. Further, there are no data on the overall level and nature of past and present university-industry interactions, and no accepted criteria for determining the optimum level and nature of these interactions. The magnitude of the problem, if one exists, is unclear.

E. Summary

The performance of basic research is increasingly concentrated in the universities and colleges, reflecting a consensus that these institutions possess a comparative advantage for that function. Industry representatives acknowledge the importance of universities as sources of trained personnel and ideas for technological development. Actual use of university research may vary by industrial sector and academic discipline.

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[70] A Report on Research in Industry, op. cit., Attachment A, p. 3.
[71] Nason and Steger, op. cit., p. 42.
[72] Pavitt, K. and W. Walker. Government Policy Towards Industrial Innovation: A Review. Research Policy, v. 5, 1976: 90.
[73] U.S. Secretary of Commerce. Advisory Committee on Industrial Innovation. Subcommittee on Procurement and Direct Federal Support of Research and Development. Draft Report on Direct Federal Support of Research and Development. Washington, 1978, p. 2.

Although universities may provide the most congenial environment for basic research, the results must be transferred to industry in order to be embodied in new and improved products and services, and thus to contribute to improved productivity. There are natural barriers between universities and industry that may obstruct this transfer, such as differences with regard to patents, publication, and freedom of research direction. Traditional modes of interaction between universities and industry, through technical societies and academic consultants, are believed to occur at low levels. Some people believe that the level of interaction has decreased over the past 25 years due to the large increase in Federal funding for university research. There are indications that this trend may be abating, while, at the same time, there have been calls for government stimulation of increased interaction. The transfer of knowledge between academic science and industrial application requires active efforts on both sides. In particular, it requires that industry recognize the value of basic research to industrial innovation.

V. Concluding Observations

Federal support for basic research in universities contributes to industrial innovation by enlarging the pool of scientific knowledge which may be used by industry in the development of new products and production processes. The utilization of basic research in innovation usually is not direct and immediate, but is indirect and delayed, often by 20 to 30 years. The main modes of transfer of basic research results are in the form of scientific information as communicated in reports and journals, and in the education and maintenance of currency of industrial scientists and engineers. Sometimes the results of basic research are transferred very quickly into applications. This usually occurs when there is an urgent technical problem which requires improved scientific understanding. Research also may be quickly transferred in the science-based industries, such as chemicals and electronics. The utilization of basic research results in industrial innovation depends not only on the supply of basic research results but also on the demand for them in industry.

The existence of institutional barriers between universities and industry may hinder the transfer of basic research results into the innovation process. Some believe that the high level of Federal funding for university research over the last 25 years has further isolated the universities from industry. Improved transfer of university research results to industry for application might increase the effectiveness of Federal research funding in stimulating national productivity growth.

Given the uncertainty, the long time to fruition, and the remoteness of basic research from commercial objectives, one would not expect a strong relationship between basic research and productivity in the near term. Economic studies have shown that the contribution of R&D to productivity is high, but these studies pertain primarily to applied research and development. Economic theory does not currently enable one to assess the precise quantitative contribution of basic research to productivity, vis-a-vis applied research and development.

The contribution of basic research seems to be primarily: (1) Improving the efficiency of the R&D process, and (2) contributing to improvements in national productivity in the long run. Basic science seems to be an "engine" for technology, without which certain innovations might be delayed or prevented, and technological progress might eventually stagnate.

Federal R&D funding is concentrated in the areas of space, health, energy, and defense and is primarily aimed at national goals other than economic productivity. Therefore, one might not expect a strong relationship between Federal R&D and economic productivity. Preliminary evidence suggests that federally funded R&D makes a negligible contribution to productivity in the near term. These findings, which appear to pertain only to applied research and development, may be due to methodological problems or the concentration of Federal R&D funds in space and defense-oriented industires. They should be regarded with caution at this time.

To summarize, for various reasons one would not expect to find a strong relationship between Federal support of basic research in universities and economic productivity in the near term, and the evidence does not in fact indicate such a relationship. Federal support of basic research in universities complements private R&D funding by providing funds where there is little incentive for the private sector to invest, and takes advantage of the natural capabilities of universities. While the private sector tends to invest in R&D projects with near-term economic potential, Federal funding of basic research in universities seeks to ensure that the supply of scientific knowledge is renewed so that productivity improvements will be possible in the long-term future.

THE DOMESTIC POLICY REVIEW OF INDUSTRIAL INNOVATION: PUBLIC INPUTS AND OUTPUTS*

CONTENTS

INTRODUCTION

In May 1978 President Carter called for a Domestic Policy Review (DPR) of Industrial Innovation. This effort, a response to widespread perceptions that industrial innovation in the United States is declining—with negative consequences for the U.S. economy and interna-

*Prepared by the Congressional Research Service, Library of Congress.

tional trade—was intended to give the issue of industrial innovation the highest level of policy attention by the executive branch. The objective was to prepare a report to the President setting forth recommendations for Federal action to enhance the status of industrial innovation in the United States. The DPR was conducted by a Cabinet-level coordinating committee chaired by Secretary of Commerce Juanita M. Kreps. Functional management of the policy review was directed by Dr. Jordan J. Baruch, Assistant Secretary of Commerce for Science and Technology.

The DPR had two phases of activity. One was an information gathering phase, in which inputs were obtained from many public and private groups and organizations. After these informational inputs were obtained, the DPR went into executive session which reportedly consisted of discussions between representatives of the various interested Federal agencies and the Executive Office of the President.

More than 150 senior representatives from the industrial, public interest, labor, scientific, and academic communities participated on the Advisory Committee on Industrial Innovation which was established as part of the DPR. Subcommittees of the Advisory Committee met during the fall and winter of 1978 to deliberate on the effects of Federal policies on industrial innovation. Policies in the following areas were considered:

Economic and trade policy;
Environmental, health, and safety regulations;
Regulation of industry structures and competition;
Federal patent and information policy; and
Federal procurement policy and direct Federal support of research development.

The Advisory Committee subcommittees produced 10 reports, addressing each of the above areas, plus the special problems of small business and labor and public interest concerns. The reports were made available in draft form to provide background for seven public symposia held in January 1979. Representatives of the industrial, labor, public interest, and academic subcommittees participated in these symposia, along with senior policy representatives from concerned government agencies. The final reports of the subcommittees subsequently were made part of the body of material considered by the Cabinet-level coordinating committee in formulating proposals for the President. They also were published by the Department of Commerce as the final report of the Advisory Committee on Industrial Innovation.[1] There appear to be only slight changes in the final report.

Nine months after the public symposia, on October 31, 1979, President Carter announced a series of industrial innovation initiatives in a message to the Congress. The reactions to the President's initiatives were mixed. Some observers said that the President's measures did not go far enough. They expressed disappointment that tax incentives and large Federal spending programs were not included. Others said that the measures went too far in weakening important protections for health, safety, the environment, and consumers. Other persons seemed to believe that the President's measures were a reasonable step in the direction of stimulating innovation.

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[1] U.S. Department of Commerce. Advisory Committee on Industrial Innovation. Final report. Washington, U.S. Government Printing Office, 1979. 299, iv.

This chapter provides a brief summary and analysis of the draft reports of the Advisory Committee on Industrial Innovation, the public symposia, and the President's Message on Industrial Innovation. It permits a comparison of the "outputs" of the Domestic Policy Review—that is, the President's recommendations—to the public "inputs" to the Domestic Policy Review—specifically the recommendations of the Advisory Committee. Such a comparison is of interest because of complaints by industry representatives that their recommendations were not heeded, and criticism by industry and Members of Congress that certain types of policy initiatives were not included in the President's message.

I. Report of the Advisory Committee on Industrial Innovation

This section summarizes the recommendations made in the draft reports of the subcommittees of the Advisory Committee on Industrial Innovation and the main points that arose during the public symposia held in January 1979. The summaries of the symposia are based on notes taken by staff members of the CRS Science Policy Research Division.[2] Lists of the symposia participants and the members of the subcommittees are included in the appendix to this chapter.

The purpose of the symposia was to provide public fora for the discussion of the impacts of Federal policy on industrial innovation, and to allow input to the Domestic Policy Review from interested members of the public. Jordan Baruch, who chaired the symposia, emphasized the need to design specific policy options for the President. Often, however, the discussion became centered on controversial issues of the benefits of innovation, the distribution of those benefits, and the relative importance of innovation as compared to other national goals represented by the labor and public interest groups. As each symposium there were representatives of the industrial subcommittee that prepared the report, the Federal agencies that would be affected, labor, public interest groups, and academia. Each subcommittee had a small business member.

The reports of the labor, public interest, and small business representatives covered the full range of policies addressed by the DPR. Therefore, their respective comments were similar at each of the symposia and have been shortened here to reduce repetition. The recommendations made in the draft reports of those groups, which were not addressed directly at the symposia, are summarized in this section.

A. Economic and Trade Policy

The Subcommittee on Economic and Trade Policy made 22 recommendations in the following primary issue areas:

For established corporations, tax disincentives to overall investment and to R&D need substantial revision, in recognition of changed economic circumstances.

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[2] William Boesman, Specialist in Science and Technology; Jane Bortnick, Analyst in Information Sciences; Robert L. Civiak, Analyst in Energy Technology; Mary Ellen Mogee, Analyst in Science and Technology, and Wendy H. Schacht, Analyst in Science and Technology.

Venture capital is in short supply for new, innovative businesses trying to establish themselves, and legislated disincentives to savings should be lessened, while certain regulatory policies are also changed, in order to alleviate this shortage.

Foreign competition, conducted legally within the United States, is a spur to innovation that must continue to be allowed, while certain government policies that restrict U.S. businesses' ability to compete abroad should be changed.

The drag on the economy created by regulatory activity must be recognized for what it is and consciously reviewed and budgeted for by the Federal Government.

While a new, large scale program of basic research directly funded by the Government is not desirable, the Government should encourage the conduct of basic research at universities and should also simplify its procurement policies to make it more feasible for small businesses to compete successfully for government contracts.

During the public symposium, the acting chairman of the subcommittee emphasized that tax, trade, and regulatory policies should be changed to increase innovation and productivity. It was stated that after-tax returns on innovation fell from 8 percent to 4 percent from the 1960's to the 1970's, due partially to the above policies. Special emphasis was placed on discussing changes in the tax code to increase cash flow and investment in innovation and to increase after-tax returns on investment. It was stated that tax changes must: (1) be feasible; (2) be understandable; and (3) not make the tax code too complicated.

The small business member of the subcommittee dissented from the otherwise unanimous report. He charged that the subcommittee failed to deal with any issues and needs of small business and the importance of small business to innovation. He warned that tax cuts do not necessarily create innovation; they must be specifically designed to do so. Some of these concerns were incorporated into the final report.

The labor representative said that a full-employment economy is needed to stimulate innovation. He opposed tax cuts to increase innovation because, he stated, they would simply provide more money to industry and not increase innovation.

The public interest representative was not convinced that there is a problem with innovation. She did not believe that the relationship between regulation and innovation has been established. She called for new methods of cost accounting and pointed out that tax cuts will not necessarily act to stimulate innovation.

One of the Department of Treasury representatives said that the recommendations of the Subcommittee on Economic and Tax Policy would need more substantiation if they were to be accepted by the President. He suggested that the following questions need to be addressed: What are the real (or possible) impacts of a tax change—will it really improve innovation? Does the export of technology really result in the export of jobs? What kinds of small businesses need what kind of assistance at what stage of the innovation process?

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A representative from U.S. Steel emphasized the importance of expected profitability to innovation. He stated that investment is undertaken because of expected profit, and anything the Government can do to increase expected profitability should be done. A Treasury representative responded that one-half of U.S. corporations had paid no Federal income tax the previous year.

Various speakers pointed out that innovation problems are usually industry-specific and specific solutions should be developed. A tax write-off would benefit companies which do not need help as well as those that do. How should policy be designed to ensure that this does not happen? Also, innovation problems vary by the stage of the innovation process—R&D, marketing, distribution, etc. One academic representative suggested that the subcommittee should be more specific on recommendations for assistance at different steps in the innovation process.

B. Environmental, Health, and Safety Regulations

The report of the Subcommittee on Environmental, Health, and Safety Regulations consisted of an overview report and three sections on safety, health, and environmental regulations. The nine main recommendations of the overview report are summarized here (additional recommendations are included in the report):

(1) The President's Executive Order 12044, to improve the regulation process, should be extended and expanded.

(2) Congress should exercise a more diligent role in oversight of regulatory agencies.

(3) Special consideration should be given to the impact of regulations on small business.

(4) The Federal Government should sponsor research to develop a better knowledge base of the "cause-and-effect" relationships in health, safety, and environmental regulations.

(5) The risk/reward ratio should be improved for innovators.

(6) The regulatory process should emphasize performance standards and cooperation rather than adversarial relations.

(7) The escalation in product liability losses should be stemmed.

(8) The Regulatory Council and the Regulatory Analysis Review Group should have some members who are well qualified in understanding the process of industrial innovation.

(9) Where possible, the public interest should be served through improved industrial consensus standards (self-regulation). Mandatory Government regulation should be a last resort.

At the public symposium, subcommittee chairman Donald Frey noted what he considered to be the most important findings: (1) The need for voluntary industrial standards in place of mandatory Government regulation; (2) the uncertainty of the scientific basis for much regulation; and (3) excessive regulatory permanency and the need for periodic evaluation and termination of unneeded regulations.

The public interest representative criticized the report severely. In her opinion, the direction of innovation, rather than its rate, should be the question in Federal policy. She stated that: (1) the Federal Government should support the kind of innovation that helps meet its legislative objectives, especially in health and safety; and (2) the priority of these goals should not be lowered. She also argued that corporate mismanagement and irresponsibility are the causes of many of industry's problems. Moreover, she pointed out that pollution control equipment currently is subject to rapid depreciation and tax credits and to delay compliance causes higher costs when it is achieved.

The labor representatives also emphasized the importance of asking the question, "innovation for what?" They said that they would tolerate no trade-offs between jobs and safety. They stated that they do not believe in cost-benefit ratios, because a worker has only one life to lose. They perceived that industry was just dragging out the old "whipping boys" to explain the slowdown in innovation.

The small business representative supported the report, but he noted that small businesses do not have the time and resources to participate in all the rulemaking procedures affecting them. Moreover, he stated, since standards apply to *classes* of businesses, the new and unique may be disadvantaged.

One of the major issues discussed was cost-benefit and risk-benefit analysis of health, safety, and environmental regulations. Industry representatives stated that these types of analyses are important and in need of improvement. As noted above, the labor representatives rejected cost-benefit analysis. In response to labor's rejection of cost-benefit analysis, Baruch said that Government has to make these kinds of comparisons because of the need to allocate scarce resources in the best manner. If labor does not participate, he said, the analysis will be done by bureaucrats.

Another major issue discussed was that of proprietary information. In the regulatory process, industrial firms are required to provide to the agencies information on health, safety, and environmental characteristics of their products and production processes. Industry fears that this information will be used by their competitors to copy their technology. Commissioner Kennedy of FDA noted that 82 percent of the Freedom of Information Act activity in that agency is actually industrial intelligence. The labor representatives emphasized the need to distinguish health and safety information from innovation information, although this distinction probably is not always clear. Another aspect of this issue is whether each manufacturer needs to characterize its own product and demonstrate its safety and efficacy, if an identical product has already been characterized by another firm.

Performance standards, as opposed to design standards, were generally recommended by industry. The Occupational Safety and Health Administration (OSHA) representative, however, pointed out that not all of industry likes performance standards because design standards may be easier to achieve. Thus, it may be preferable to combine performance and design standards.

C. Regulation of Industry Structure

Although the Subcommittee on Regulation of Industry Structure considered primarily economic regulation and antitrust policy as they affect industrial innovation, considerable attention was given also to health, safety, and environmental regulations. The subcommittee report identified seven issues and recommended accompanying courses of action for each. The seven issues were:

(1) Inconsistency of regulation reduces innovation.

(2) Innovation is negatively impacted by regulating the means rather than the ends.

(3) Regulation of price and entry impedes innovation.

(4) Unconsidered economic impacts of regulation impair industry viability and weaken world market positions.

(5) Costs of regulation lead to increased market concentration.

(6) Antitrust policies can inhibit innovation.

(7) The American market is but a component of the world market—and it should be so perceived by antitrust authorities.

Comments from the industry participants in the public symposium underscored the following points made in the subcommittee report about antitrust policy:

(1) Antitrust policy has an indirect effect on innovation. It may inadvertently alter the risk/reward structure for innovation.

(2) Congress and the agencies should give more attention to impacts of antitrust policy on innovation.

(3) Section 7 of the antitrust legislation should treat foreign and U.S. acquiring firms the same.

(4) Antitrust enforcement should be carried out in the context of national economic policy. A general relaxation of antitrust enforcement is not called for.

The labor representative emphasized at the public symposium that an expanding, full-employment economy is necessary for innovation. He was concerned about the possible damaging effects of innovation on workers in terms of loss of jobs and income. He also pointed out that many of the Nation's economic problems are due to oil imports and the recession, not innovation. He recommended that workers be provided with information on planned innovations in advance. He also recommended relocation assistance and supplemental unemployment insurance. He was opposed to tax cuts, tax credits, accelerated depreciation, and so on. Rather, he stated that the Government should use selected expansionary economic policies while trying to achieve full employment and equal opportunity. He claimed that exports of technology and jobs through multinational corporations have hurt the United States.

The public interest group representative stressed the importance of the direction of innovation and was concerned with the social and economic significance of innovation. She described the public interest framework for considering innovation issues. It involved asking such questions as, "What does innovation mean to the Nation as a whole, should government take a role in innovation, what are the criteria for that role, and innovation for what?" She stated that the Government should support only socially beneficial innovation. It should ask, "How beneficial is this innovation and for whom?" She called for "public accounting" for innovation with improved quantitative social indicators. She recommended a continuing Federal role to assure that social and economic implications of innovation coincide with social goals.

A representative of academia suggested a flat injunction against joint research among large industrial firms, but stated that individual cases could be negotiated for smaller firms. She felt that the use of market share as the sole indicator of monopoly might remove incentives to innovate. She called for university-industry-Government cooperation in educating for innovative management.

The Department of Justice representative said that he believed the subcommittee report was moderate, balanced, and cogent, although he did not agree with all of it. He stated that it expressed a viewpoint that should be continuously reevaluated. He stressed that competition as a basic force in the economy should be maintained; the question was which mechanisms are best to preserve this and which are counterproductive? He suggested three questions to be considered by the panel members:

(1) Given that innovation and competition are intermediate goals, what is the mechanism in terms of enforcement decisions that permits these considerations to be weighed?

(2) International effects are given consideration in Justice decisions, but how much competition are we willing to do without domestically in order to enhance our foreign competitiveness? How can this question be handled?

(3) Of what use would be an interdepartmental task force to sit on particular cases?

One of the main issues discussed at the symposium was joint research by corporations. Industry representatives argued that uncertainty about antitrust enforcement hinders innovation. The Justice representative described the business review procedure used when a firm asks Justice for its enforcement intention—in effect to obtain advance clearance. In the last year or so, he said, Justice has received 29 requests to conduct joint R&D and has cleared 90 percent of them. In this process a detailed memorandum is prepared which includes a discussion of likely effects on innovation. The Justice representative noted that there appears to be a problem in the *perception* of antitrust policy. Assistant Secretary Baruch suggested that it is the Federal role to make things more clear.

Another issue discussed was the need for interagency coordination of regulations, especially in cases where several agencies share jurisdiction and are promulgating regulations. The Justice Department representative stated that the agency involved must be responsible for the regulations it promulgates. He also was skeptical about how well an interagency body would work. The public interest group representative was concerned that such interagency bodies might be less accessible to the public.

With respect to technology exports, an industrial representative pointed out that foreign technology has been developed largely independent of the United States and not primarily due to U.S. technology transfer. He also pointed out that foreign exports create nine jobs in the United States for every foreign job.

D. Patent Policy

The Subcommittee on Patent and Information Policy concluded that the United States patent system is functioning well and is in need of only incremental changes. The subcommittee made three major recommendations to improve reliability of the patent grant. They are:

(1) Upgrade the Patent Office by:
   (a) Providing an adequate examining staff to assure a rigorous, high quality examination. This would increase confidence in the patents that are issued.
   (b) Providing modern search tools that increase the probability of finding the relevant prior art. This would be a cost-effective investment by reducing search time per examiner, as well as reducing the frequency of subsequent proceedings to argue the prior art.

(2) Provide a reexamination process—available to all interested parties—in order to ensure that the patentability of the invention described in the patent has been considered by the Patent Office in the light of all relevant prior printed publications.

(3) Provide a central court to hear patent appeals. This would provide greater *consistency* in judicial decisions, thus reducing uncertainty.

Other recommendations also were made to stimulate innovation, but apparently were not unanimously supported by the subcommittee. These included, for example, extension of the current 17-year patent term. In order to avoid duplication with the Office of Science and Technology Policy committee working in this area, the public symposium did not devote much discussion to the issue of government-owned patents. However, the subcommittee stated that the private sector must have exclusive patent rights, while the Government should retain rights for its own use.

The major problem with the patent system, as summarized by a representative from Hughes Aircraft, is that many patents today are unreliable—that is, they will not stand up in court against infringement actions. Therefore, it is necessary to upgrade the Patent and Trademark Office to permit better examinations that will result in examination tools, specifically computer information systems and more reliable patents. The main thrust of the discussion of upgrading the Patent and Trademark Office centered on the need for better examination tools, specifically computer information systems and automation. There also was a significant amount of discussion on the reexamination process which consumes a large amount of resources.

A representative of small business called for longer patent terms for small businesses. He also called for a patent counselor in the Small Business Administration. He suggested the Connecticut Product Development Corporation and Great Britain's National Research and Development Corporation as examples of how to get Government-owned patents commercialized. He stated that inventors should get a large share of the benefits from their inventions.

A labor representative objected strongly to the transfer of Government-owned patents with exclusive rights to the private sector. He stated that exclusive rights are not necessary and that present Government-granted license rights are generous enough. Another labor representative stated that Government should not try to reform the patent system because that would only be tinkering. What is needed to stimulate innovation, he said, is an expanding economy.

The public interest representative also objected to the transfer of Government patents to the private sector. Further, he strongly questioned the premise of declining U.S. industrial innovation. He did not agree that the patent system is functioning well. He did not want a court of appeals because it would further clog the judicial system. He was in favor of shortening the patent life because he believed that patents are being used to stifle innovation and protect the status quo, rather than to promote invention and innovation. He also asserted that vertical and horizontal integration in industry kills innovation, and he cited with approval Sen. Kennedy's antimonopoly efforts.

E. Information Policy

The draft report on Information Policy contained the following summary of the principal recommendations of the Subcommittee on Information Policy:

Patents as a Source of Information

The Patent Office should complete the development of an effective computer-based search and retrieval system for its own use and for public access, and should support the development of appropriate classification and indexing schemes in order to integrate the systems for the various technologies. The Patent Office should also develop specifications for and require the submission of supplemental information concerning a patent's use and potential applications.

Foreign Market and Technical Information

The U.S. Government should make arrangements for foreign countries to provide U.S. companies with information on standards and product approval requirements. Especially, it should encourage international technology transfer through negotiations with various international bodies; by resisting restrictive regulations by foreign countries or international agencies; and by clearly stating its intent to continue to permit such transfers for commercial applications. Further, it should encourage and help make possible the systematic collection and distribution of foreign patents.

The Government should prevent the imposition of countervailing duties by the U.S. Treasury Department on products benefiting from foreign government R&D subsidies.

Regulatory Impediments, Including the Freedom of Information Act

Congress should amend the Freedom of Information Act to make clear that information which is classified as described in Sub-section 552(b)(4) of the Act shall not be released under the Act.

Protection of Data Bases and Software

The Commission on New Technological Uses of Copyright Works (CONTU) recommendations relative to copyright to software and data bases should be implemented.

Government as a Creator and Distributor of Information

Government should establish a policy that, except for confidential and classified materials, all information created and collected by the Government should be made conveniently accessible at incremental costs to help widen its distribution and use.

A more productive Government-industry relationship should be secured by establishing the policy that the Government will refrain from entering into competition with existing services without a clear demonstration of public need and will work with the private sector to help fill information gaps. Government should encourage the wider dissemination of innovation related information from Government resources and assist in filling the needs for innovation related data.

The general findings of the Subcommittee on Information Policy, as reported at the public symposium, were that information is very valuable in the process of innovation, especially information on ongoing R&D and information to evaluate the risks of information. Moreover, information must be communicated in time frames and formats needed by the innovator. People must know that it is available. Some of the current problems are:

The lack of information on patents;

The lack of technical information from foreign nations; and

The lack of information services specialized for referrals and location of information sources.

It is necessary to assist the user to find and use the information.

Labor representatives said that information on innovation should be directed toward small business, high unemployment areas, and other areas of need. They were concerned with the loss of jobs in the United States that may result from international technology transfer.

The public interest representative repeated the concern that the direction, not the rate, of innovation was important. She was concerned with the impact of innovation on the quality of life. She cited the need for public accounting for innovation, including social and financial indicators.

The academic representative emphasized the importance of informal, verbal communication channels as opposed to written and electronic means. He recommended personnel exchange programs.

There was a lengthy discussion of how to develop the patent data base in the Patent and Trademark Office. There was no consensus, but options were identified to improve technical data on patents. Some of the questions were whether the data base should be Government-sponsored or commercial and whether it should be just a data base or an information system with software. It was noted that the importance of patents as a critical source of technical information in the innovation process varies by field, so that specialized data bases would be needed.

Options were also identified to improve information on international markets. The World Information and Trade System (WITS) was mentioned as being developed in the Department of Commerce to provide information on foreign markets to U.S. industry.

F. Federal Procurement Policy

The Subcommitee on Federal Procurement Policy made 18 recommendations, broken down into the following seven categories:

(1) Overcoming barriers to innovation;

(2) Reform of Federal procurement policy;

(3) Strengthening independent research and development (IR&D) by Federal contractors;

(4) Protection of Federal contractors' patents;

(5) Protection of Federal Contractors' Proprietary data;

(6) Increasing basic R&D in universities, Government laboratories, and industry in support of industrial innovation; and

(7) The use of procurement to create markets for innovation.

Thomas Paine, chairman of the subcommittee, presented three main conclusions:

(1) There is a need to change attitudes of regulatory agencies from restriction to stimulation of innovation.

(2) The promulgation of OMB Circular A–109 is a welcome step in the right direction.

(3) The cost of implementing the subcommittee's recommendations will be minor compared to the potential savings.

He also noted that the two top priority recommendations pertained to Circular A-109 and IR&D, respectively.

One small business representative stated that all 18 recommendations were beneficial and was very happy with them. Another, however, reported that he had asked 28 small business leaders whether the recommendations would lead to an innovation renaissance, and the answer was no.

The labor representative said that Federal procurement policy should be used as a tool to support freedom, democracy, and the well-being of citizens, not just the well-being of corporations. He held that firms that do not deal fairly with labor should not receive Government contracts. However, he generally supported the use of procurement procedures to support innovation, although he disagreed with a recommendation pertaining to patents obtained under Government funding.

The public interest representative supported many of the procurement policy recommendations, especially those with regard to common use items. He said that test information should be disseminated and that life cycle costs are important. He objected to the recommendation that contractors be allowed title to patents developed with Government funds, arguing that the public interest demands that these patents be held by the Government for the public good.

On being asked what changes in policy would help them, a General Services Administration representative commented that they would like more flexibility to make purchases using criteria other than lowest cost. It was noted that there is a problem of public accountability with public funds, to which lowest cost criteria are a response.

Independent R&D was a major topic. There was a discussion of the difficulty of separating IR&D costs from bid and proposal (B&P) costs. An industrial representative said that "independence" leads to poor R&D. A DOD representative said that "independence" leads to use of funds for bid and proposal, rather than R&D. The purpose of IR&D is to allow the firms to take the long-term view, but economic and inflationary problems often force firms to take the short-term view, according to industry representatives. Industry resists the evaluation of IR&D by the sponsoring agency and the application of the criterion of potential military relevance. DOD was in favor of evaluating the contractor's IR&D. NASA, on the other hand, said it set a limit on the amount of funding allowed for IR&D, but let market competition ensure the quality. There was a complaint from one industrial representative that IR&D and B&P funding gives the recipient an unfair advantage in competing for the next contract.

G. Direct Federal Support of Research and Development

The draft report of the Subcommittee on Procurement and Direct Support of Research and Development identified three main areas where industrial innovation could be accelerated:

(1) University-Industry Relations. The Government should encourage direct coupling of university research to industry

needs by giving matching grants to industry to be recommitted to research in universities.

(2) Incentives for Technology-Based Ventures. The panel was unable to agree on a single mechanism, but suggested three prototypes: The National Advisory Committee for Aeronautics (the predecessor agency to NASA), the Federal Housing Administration, and agricultural experimental activities in State land grant colleges.

(3) Support of R&D on Generic Technology. Direct Federal support of R&D and dissemination of new technology generic to process or product innovation in a wide spectrum of U.S. industry should be strengthened and recognized as Federal policy. Federal support would involve the development of a coordinated network of cooperative technology centers.

At the public symposium, a subcommittee representing small business recommended: (1) that 10 percent of Federal R&D funds be targeted to small business and (2) that the Small Business Administration administer a small business innovation program. Another subcommittee member said that the real problem of innovation is that venture capital has dried up because of the tax structure. A third member of the subcommittee noted that industrial innovation would be stimulated if industrial money for R&D would replace Government money. He said that dramatic programs are not needed, but rather agreement on the importance of industrial innovation as a long-term goal.

A labor representative said that tax credits (one suggested means of funding cooperative university-industry research) were a raid on the U.S. Treasury and that a healthy economy and full employment are more important than direct support of R&D in stimulating innovation.

The public interest representative repeated many of the points made by his counterparts at the other symposia. The most important of these was the contention that the *direction* of innovation is more important than its *rate*. Government should first ask, "innovation to what end?" Social and ethical goals should not be compromised by economic imperatives, although progress toward these goals is more difficult to measure than economic progress.

An academic representative charged that the subcommittee had not established where the linkage problems between R&D in universities and industry occur, and that without a properly specified problem a recommendation could not be made. He advocated more targeting of the aid, stating his belief that only certain kinds of high-risk R&D need to be supported by the Government.

A representative from Battelle noted that nonprofit organizations such as his currently are filling the university-industry gap. A representative from the Textile Research Institute noted possible problems in protecting proprietary information.

Assistant Secretary Cutler of the Department of Agriculture pointed to the experimental stations as a model to stimulate innovation. However, it was pointed out that it would take large funding over a long period to duplicate this program in other industries.

There was some disagreement on the role of peer review in university-industry cooperative research, how long term the research should be, and how particular projects should be selected.

H. Small Business Recommendations

The small business members of the subcommittees of the Advisory Committee on Industrial Innovation prepared a report on the specific impact of Federal policies upon innovation in small businesses, and how Federal policies might be revised to stimulate innovation in that sector of the economy. The report was premised upon the belief that small businesses make a large contribution to innovation, and the policies, laws, regulations, and procedures of the Federal Government impose a heavy burden upon small business innovation. Their seven recommendations are summarized below:

(1) Changes in the Federal tax code to again encourage the flow of capital into small innovative businesses;
(2) Changes in Employment Retirement Income Security Act (ERISA) policies to return a portion of the national flow of savings to high-risk innovation;
(3) Changes in security laws and regulations to remove obstacles for innovative enterprises to acquire seed, startup, and expansion capital;
(4) Changes in regulatory policies to remove adverse discrimination against the small innovator;
(5) Changes in Federal R&D funding policies to produce substantially greater results by awarding a larger share to small businesses;
(6) Changes in Federal procurement policies to allow greater participation by small businesses on a more equitable basis; and
(7) Strengthening the Nation's patent system, and making changes in Federal policies to recognize and protect initial exclusivity as an essential requirement for successful innovation.

I. Labor Subcommittee Recommendations

The Labor Subcommittee made three key points in its report:

(1) The best stimulus for innovation comes from a healthy, full-employment economy—not from tax breaks and not from weakening protections for workers' health and safety, for consumers, and for the environment.
(2) Workers and their unions have reasonable, legitimate concerns about loss of jobs and income caused by innovation. Healthy economic growth provides the incentives for innovation and the resources for human social adjustment to innovation.
(3) Collective bargaining can ease many of the problems created by innovation. An early warning system involving labor, business, and government could improve labor-management and other social adjustments to innovation and changing technology.

The Labor Subcommittee recommended a joint program to assure workers an "early warning system" of advance information about management plans for future innovations which might affect workers with job loss or other problems. The committee also called for the

Federal Government to establish a clearinghouse to gather, on a continuing basis, information on innovation and its effects on jobs, skills, training needs, and industry location. It also suggested extension of Federal programs to ensure full employment and worker adjustment assistance.

The Labor Subcommittee opposed easing business taxes to stimulate industrial innovation. It recommended instead selective, expansionary economic policies. The subcommittee opposed weakening environmental, health, and safety regulations in the name of industrial innovation. It called for increased Federal funding and staffing for regulatory agencies.

The Labor Subcommittee called for controls on technology exports and imports and on the foreign operations of U.S.-based multinational corporations. It also called for an end to incentives to foreign direct investment.

The Labor Subcommittee supported recommendations in the area of Federal procurement policy and patent policy, but opposed granting of title to private contractors for patents funded by the Government. The labor representatives generally supported the recommendations in the area of information policy, but urged guidelines for international flows of information.

The Labor Subcommittee called for a congressional investigation of the effects of business concentration on competition and innovation. It supported the Federal chartering of large corporations and strict enforcement of antitrust regulations.

J. Public Interest Subcommittee Recommendations

Several of the main points of the Public Interest Subcommittee have been noted previously in the discussion of the public symposia. Some of these points are the conviction that the direction of innovation is more important than its rate; that important social goals such as health, safety, and the environment should not be sacrificed to the economic concerns implied in the innovation issue; and that the Federal Government should only encourage innovation that it determines is in the public interest. Moreover, the Public Interest Subcommittee was unconvinced that there is an industrial innovation problem that warrants Federal assistance. Despite these reservations, the subcommittee made 21 recommendations for directing industrial innovation toward important social objectives. These recommendations fell into the following categories:

(1) Policy and coordination at the Federal level;
(2) Exemplary role for the Federal Government;
(3) Reform of the voluntary standards-setting process;
(4) Reform of the patent system;
(5) Small business and competition;
(6) Alternative forms of enterprise;
(7) Alternative technology;
(8) Consumer participation;
(9) Defense spending and conservation; and
(10) The effects of innovation on workers.

II. The President's Message on Industrial Innovation

A. *Introduction*

In a message to the Congress on October 31, 1979, President Carter announced a series of measures designed to "help ensure our country's continued role as the world leader in industrial innovation."[3] His message was a result of the Domestic Policy Review of Industrial Innovation. This section presents a brief summary and analysis of the President's innovation initiatives. The initiatives, which the President called "an important first step," fell into nine areas:

(1) Enhancing the transfer of information;
(2) Increasing technical knowledge;
(3) Strengthening the patent system;
(4) Clarifying antitrust policy;
(5) Fostering the development of small innovative firms;
(6) Opening Federal procurement to innovations;
(7) Improving our regulatory system;
(8) Facilitating labor-management adjustment to technical change; and
(9) Maintaining a supportive climate for innovation.

The President's Message on Industrial Innovation and the accompanying Fact Sheet are included in the appendices to the Research and Innovation Area Study volumes.

The initiatives are relatively low-key and do not appear to represent a major thrust on the part of the Administration. The first year budget (fiscal year 1981) request for all of the new programs together was about $55 million, and it was not clear how much of this represented new budget authority. The President's budget revision resulted in some cuts in the innovation initiatives. Most of the innovation measures do not involve new legislation; perhaps two to four pieces of legislation will be requested by the Administration.

The initiatives are perhaps most notable for what they omit. No tax proposals were submitted. Administration officials explained that tax proposals would be considered later in the context of the President's overall economic and tax policy proposals. At this time, it seems unlikely that the President will support tax changes. Tax proposals to stimulate capital formation and investment in R&D and innovation are considered by many knowledgeable persons in this field to be the single most important stimulus possible to innovation. Although the initiatives range across a broad spectrum of policy areas, there does not appear to be, on the surface, a framework or logic for how they are supposed to hang together. In other words, there does not appear to be a coherent Administration strategy of which these initiatives form a part.

The implications for the Congress of the President's innovation initiatives are of two basic kinds. First, the Congress will be called upon to deal with legislation requested by the Administration. It appears that this legislation will be primarily in the areas of patent

[3] U.S. Congress. House. Industrial Innovation. Message from the President of the United States, Transmitting Proposals for Fostering Industrial Innovation. Washington, U.S. Government Printing Office, 1979, 8 p. (96th Congress, 1st session. H. Doc. No. 96–214.)

reform and budget authorizations for fiscal year 1981. Second, the Congress may wish to consider the adequacy of the President's initiatives for dealing with the perceived problem of industrial innovation. For instance, congressional critics have voiced dismay that no tax policy proposals were included in the package and a number of tax proposals related to R&D, innovation, and capital investment generally, have already been introduced in the 96th Congress. A large number of additional policy proposals to stimulate innovation through a wide variety of mechanisms including tax policy, patent policy, regulation, antitrust, Federal R&D funding, and Federal procurement have been made recently (and over the last 10 to 15 years) by industry, government officials, and academics. The Congress may wish to consider some of these proposals in addition to those submitted by the President. The Congress may also wish to develop a more systematic strategy for dealing with the complex problem of engaging in coordination and liaison activities between the Members and Committees with interest and jurisdiction in related areas. At this point, further action in the area of industrial innovation effectively seems to rest with the Congress, assuming that Congress chooses to act.

The rest of this section deals with each of the nine measures specifically discussed in the President's message on industrial innovation and with tax policy, an area relevant to innovation which was deferred by the President. This section concludes with a brief discussion of reactions to the President's message on industrial innovation.

B. Enhancing the Transfer of Information

The President's message provides two new initiatives for enhancing the information transfer aspect of industrial innovation. Both of these proposals involve expanding the role of the National Technical Information Service (NTIS) for collecting and disseminating technical information to industry. While these recommendations should improve the amount of scientific and technical information collected and disseminated, they do not insure the effective stimulation of innovation in the United States. Key to enhancing innovation are the development of appropriate information transfer mechanisms and more effective integration of the information into the entire technology utilization process.

Several key areas where improvements in information transfer mechanisms could be beneficial were not presented. Included would be such things as:

Better consolidation and coordination of existing scientific and technical information (STI) systems operated by the Government;

Improvements in the classification of materials and better standardization of formats and protocols (domestic and international);

Greater utilization of modern information technology for facilitating the transfer process; and

Better mechanisms for interfacing the public and private sectors to improve user feedback on the utility of types of data and transfer systems.

The recommendation concerning interviews of returning U.S. overseas visitors appears particularly weak in light of the need for unbiased technical data. Coordinated efforts could be made through international agreements—both bilateral and multilateral—to improve the inflow of useful STI from abroad which might benefit U.S. industry more directly.

The President's recommendations in the information field will impact most directly on the operations and mission of NTIS. As a result, future congressional deliberations on new authorizations or appropriations for NTIS may have to consider the President's recommendations in light of NTIS' ongoing need to be financially self-sufficient, the emphasis on coordination and consolidation of information products and services within the Government, and the current initiatives for domestic technology transfer.

C. Increasing Technical Knowledge

The second area, entitled "increasing Technical Knowledge," builds on the tradition of direct Federal funding for R&D as a means of stimulating innovation. It should be noted, however, that many students of innovation believe that the availability of new technology is not a major problem; they claim that much unused technology lies "on the shelf" awaiting changed economic conditions that will provide an opportunity for its use. This point of view also holds that if new technology is the solution to the problems of a firm or industry, the firm or industry will develop the new technology. Proponents of direct R&D funding, however, argue that, in some instances, the economic incentives are insufficient to stimulate innovation, the resources do not exist, or the risk is too high, thus justifying Federal involvement. It is probably reasonable to include incentives to increase technical knowledge as part of a balanced policy to stimulate innovation.

The Fact Sheet accompanying the President's message [4] describes three initiatives in this area: (1) Generic technology centers; (2) regulatory technology development; and (3) improved industry-university cooperation in R&D. President Carter proposed the establishment of generic technology centers (jointly funded by industry and government, at universities or other private sector institutions) to develop and transfer technologies common to a number of industries. This was done because of the widespread perception that there are a number of these important generic technologies that need to be developed and more widely applied, such as welding and joining, robotics, and corrosion prevention and control; that individual firms will underinvest in these technologies because the benefits to any single firm will be small; and that these technologies can be significantly upgraded. It is also believed that this mechanism offers the opportunity to use to greater advantage the capabilities of universities in improving industrial technology.

Some of the issues raised by the proposed centers include the question of administrative arrangements—how will authority and responsibilities be shared by industry, academia, and Government? The balance of power in these arrangements may affect the nature of work

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[4] See the Appendices to this report for the President's message and the fact sheet.

done in the centers and its ultimate use in industrial operations. There is also a question of conflicts with antitrust policy. The Department of Justice has indicated that, in some circumstances, use of the centers by firm with large market share could be viewed as an infraction of antitrust law. There is also a question of how well this type of activity will fit into the university environment, which traditionally has been oriented toward fundamental research and publication.

The second intiative in this area, which is mentioned in the Fact Sheet but not in the President's message, is to ask the Office of Management and Budget to examine closely the nature and extent of Federal expenditures on regulatory compliance technology and to bolster the Federal effort. Some students of regulation have called for enhanced Federal support of development of compliance technology as a major component of environmental policy. They claim that such support is necessary, especially for firms and industries in which the cost of new technology is high relative to assets. This is part of a growing concern over the high economic costs associated with achieving environmental goals. Other persons object to increased Federal support of compliance technology, asserting that private industry must pay for the environmental damages caused in years past. From an analytical perspective, it may be difficult to determine in what areas Federal support should be given priority. Since the President did not mention this initiative specifically in his speech and a specific figure is not given for an increased funding level, the probability of significantly increased Federal funding for compliance technology is difficult to assess at this time. Additional regulatory measures were proposed under "Improving Our Regulatory System," discussed in a later section of this paper.

The third area of presidential initiatives in this area is improved industry-university cooperation in R&D. The rationale for this initiative is that the "scientific and technological strength of American universities has not been harnessed effectively in promoting industrial technological advance." Therefore, increased funding for an NSF program of support for joint industry-university R&D is proposed. Some of the same issues of administrative arrangements mentioned in the discussion of generic technology centers pertain here. Other issues include possible problems in scaling up the existing NSF program (from a level of about $5 million to about $25 million per year) and possible constraints on the program due to the NSF's traditional orientation toward basic research. The President proposed to extend the NSF program to other agencies in future years, with the objective of eventually spending about $150 million in this way.

The Congress is currently considering two bills, S. 1250 and H.R. 4672, which would establish centers for industrial technology which are substantially similar to the generic technology centers proposed by President Carter. These bills were introduced and hearings held in 1979; further action is expected in 1980. Establishment of the generic technology centers in the Department of Commerce and the National Science Foundation probably would require congressional authorization. It is not clear at this time how much of the proposed funding would require new budget authority and how much would be reprogrammed. The initiative on regulatory technology development evidently would not require congressional action in the 96th Congress.

If the Office of Management and Budget concludes from its examination of the budget that Federal expenditures on regulatory compliance technology should be increased, the Congress likely would review the proposed expenditures in the fiscal year 1982 budget. The proposed increase in the NSF program of joint industry-university R&D would require congressional authorization of the fiscal year 1981 budget.

D. Strengthening the Patent System

The measures announced by President Carter in the area of strengthening the patent system fall into two major categories: (1) The ownership of inventions resulting from federally funded R. & D. and (2) a general revision of the U.S. patent laws. Both areas of concern have been addressed by the Congress for a number of years, but without the enactment of comprehensive legislation on the subjects. In the 96th Congress, several bills on both subjects have been introduced.

OWNERSHIP OF INVENTIONS RESULTING FROM FEDERALLY FUNDED R. & D.

U.S. Government agencies generally retain title and rights to inventions resulting from federally funded R. & D. (generally about 50 percent of the Nation's entire expenditure), made either by Government contractors, grantees, or in-house Government employees. The President's message addressed the major issues involved in the ownership of inventions resulting from federally funded R. & D., which are: (1) whether the Government uniformly should take title to inventions derived from federally funded R. & D., thereafter licensing the inventions to potential users; (2) whether such licenses should be exclusive (permitting only one user) or nonexclusive; (3) whether, like some Government agencies, the Government in general should waive its rights to such inventions, providing that the Government's investment is safeguarded by the Government's royalty-free use for its own purposes and by "march-in-rights" to ensure that if a user does not, in fact, use the invention, other users may be licensed or the waiver can be terminated; (4) what the Government's rights are in contractor- or grantee-developed patents covering related inventions made by the contractor or grantee before or outside of the contract or grant effort in question ("background patents"); and (5) whether a comprehensive, Government-wide patent policy is required. There is not now such a uniform Federal patent policy.

There currently seems to be a strong movement toward enacting legislation: (1) to waive Government patent rights and/or to grant exclusive rights in specific cases to private firms and individuals, providing that there are strong Government march-in rights and other safeguards to protect the Government's R&D investment; and (2) to make this a comprehensive, Government-wide policy. In the 95th Congress, the "Thornton bill," introduced by Representative Thornton, incorporated such features. Extensive hearings were held on this bill by the House Committee on Science and Technology in that Congress, but no legislation was enacted. In the 96th Congress, a bill similar to the Thornton bill has been introduced, as have bills that incorporate some of the Thornton bill's features with specific reference only to

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universities, nonprofit institutions, and small businesses. In short, the measures discussed in President Carter's message are largely incorporated within bills already introduced in the 96th Congress and for which there seems to be significant support both in Congress and the private sector.

GENERAL REVISION OF THE PATENT SYSTEM

There seems to be a widespread belief that a number of aspects of the existing U.S. patent system need to be improved. Major legislation in the 94th Congress (S. 2255) was introduced on this subject, but not enacted. Similar legislation was not introduced in the 95th Congress; several bills on this subject have been introduced in the 96th Congress. A general revision of the patent system would benefit technological innovation by streamlining the processes by which many inventions are incorporated into the industrial innovation process. Most observers apparently believe that revision of, or significant improvements in, the patent system, generally in line with the President's message, would be a particularly useful contribution to technological innovation.

E. Clarifying Antitrust Policy

The President listed the clarification of antitrust policy as one of the "critical areas" surrounding the major issue of industrial innovation. Because, as he stated, "our antitrust laws are often mistakenly viewed as preventing all cooperative activity," the President indicated that he would request that the Department of Justice issue a "guide clearly explaining its position on collaboration among firms in research" and would request a "broader program of improved communication with industry by the Justice Department and the Federal Trade Commission."

The Antitrust Division of the Department of Justice currently has indicated its proposed enforcement activities in the areas of mergers (Merger Guidelines) and international activities (Antitrust Guide to International Operations). The Department also currently operates a Business Review Procedure, pursuant to which firms may submit proposals for assessment and an indication of the Department's enforcement intentions. The Business Review process is "transaction specific," however, and could be supplemented usefully by a general joint research and development guide, which would probably do much to disseminate the Department's philosophy of antitrust enforcement in that area, likely dispelling some of the uncertainty and apprehension currently felt by the business community.

Speeches by members of the Antitrust Division have given some indication of the Division's interpretation of the antitrust laws as they interact with business' desire to engage in joint research and development activities. "The concern of antitrust policy is to properly balance the possibility that firms can better achieve a particular technological end through collaboration. . . . Although the antitrust laws prohibit only those joint ventures which unreasonably restrain trade, economic evidence indicates that economies of scale in R. & D. may not be presumed, and thus that joint activities may frequently be unnecessary for innovation by firms of moderate size."[5] Nevertheless, a formal guide setting forth some of the particular considerations deemed relevant to the Department's decision whether to prosecute a particular joint R. & D. activity (and perhaps presenting some hypothetical scenarios, as does the Antitrust Guide to International Operations) would likely be helpful to the business community. So, too, would regular communications between the Department and members of the business community, and the Federal Trade Commission and members of the business community.

Probably no major new legislation is required in order to carry out the goal of clarifying antitrust policy vis-a-vis R. & D. and innovation. The Congress, rather, will probably choose to oversee the activities of the several involved executive branch departments and agencies (like the Departments of Justice and Commerce and the Federal Trade Commission) to determine whether they, in fact, are carrying out the intent of the President's message. If this intent is carried out, probably most of the perceived problems involving antitrust aspects of industrial R. & D. and innovation either will be ameliorated or brought into sharper focus for specific congressional or executive branch action.

F. Fostering the Development of Small Innovative Firms

The President, in his message, noted that small businesses have historically played an important role in bringing new technology to the market place and in providing new jobs. Moreover, small innovative businesses have been hurt disproportionately by reductions in the availability of venture capital in the 1970's and by the costs of regulatory compliance. For these reasons, it is widely believed that small innovative businesses are especially deserving of Federal assistance.

The President's message mentions two initiatives in this area. One is to enhance the NSF's Small Business Innovation Research (SBIR) Program by $10 million. (The NSF will also assist other agencies in implementing similar programs, with total funding eventually to reach $150 million per year.) The Fact Sheet mentions that the existing SBIR program has been praised by many and has resulted in projects for which follow-up private-sector funding has been pledged. No public, formal evaluation of the program has been conducted, however. A general issue to be considered in providing venture capital for innovation, and one that remains unsettled in the case of the SBIR, is whether public funds drive out private funds that would otherwise be available. If this is the case, then Federal funding does not result in a net increase in venture capital availability. Other issues that should be considered are possible problems in scaling the existing $2.5 million activity to a $10 million activity in one year and possible constraints placed on the program due to the National Science Foundation's traditional orientation toward the support of basic research at universities.

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[5] Ewing, Ky. Deputy Assistant Attorney General, Antitrust Division, "Competition and Innovation: The Creative Relationship," speech presented to National Association of Manufacturers, Mar. 29, 1979.

The second initiative mentioned in the President's message is the establishment of two Corporations for Innovation Development (CID) to provide equity funding for new small firms that will develop and market promising high-risk innovations. The message states that these not-for-profit corporations will be established with State or regional capital and the Federal Government will provide each with matching loan funds up to $4 million. The CID's will be modeled partly after the National Research and Development Corporation (NRDC) in Great Britain and existing state corporations, such as the Connecticut Product Development Corporation. It appears that only two CID's are planned, since no plans for additional CID's are mentioned and the stated purpose is "to lead the way for States or regions to establish CID's." The achievements and effectiveness of existing programs should be carefully evaluated in establishing and administering the CID's.

A third initiative mentioned in the Fact Sheet, but not in the President's message, concerns the participation of small R. & D. businesses in Federal R. & D. procurements. The Fact Sheet states that "the small business community correctly believes that given their number, and the significance of their role in the innovation process, they receive a disproportionately low percentage of Federal R. & D. dolars." Therefore the President directed all Federal R. & D. agencies to: (1) develop policies to ensure that small businesses are not unfairly excluded from competition; (2) publicize opportunities for small businesses to participate; and (3) report their progress toward increasing small business participation annually to the Office of Management and Budget. This measure is of doubtful priority since it did not appear in the President's message itself. It has been criticized as being too weak by some Members of Congress who favor setting some percentage of an agency's R. & D. budget that must go to small businesses. On the other hand, most agencies oppose stronger measures, such as quotas, because they increase the constraints within which the agencies must administer their programs. Moreover, the agencies claim that the administrative costs and uncertainties of dealing with a large number of small firms are higher than those of dealing with a smaller number of large firms.

Congressional authorization would be required for the proposed increases in the NSF's Small Business Innovation Research Program for fiscal year 1981. Authorizations for similar programs in other agencies may require congressional authorizations in future fiscal years. Similarly, the establishment of the Corporations for Innovation Development, through the Department of Commerce, would require congressional authorizations in the fiscal year 1981 budget. The President's initiatives with respect to Federal support for small R. & D. businesses probably would not require congressional action. S. 1074, introduced by Senator Kennedy in the 96th Congress, addresses the same problem, but sets minimum percentages of each agency's R. & D. budget which must be allocated to small businesses.

G. Opening Federal Procurement to Innovations

The President's Federal procurement initiatives express the belief that the procurement process can assist in stimulating the development of innovative products and services. The substitution of "performance" for "design" specifications, as well as considerations of life-cycle management costs over initial purchase price, are two prime foci of the President's initiatives. An elaboration of this policy directs the Office of Management and Budget's (OMB) Office of Federal Procurement Policy to introduce reforms in Federal procurement practices by establishing uniform procurement policies and regulations. Responsibility for expediting and implementing reforms is to be given to a designated senior official within each Federal agency. In addition, the General Services Administration is directed to expand the New Item Introductory Schedule to improve and publicize new items.

The shift from design to performance or functional specifications in procurement, while a perceivable trend, represents a change of emphasis among certain Federal agencies. There seems to be a consensus that performance specifications serve to stimulate innovation by allowing more diversity in design. It is suspected, however, that implementation of this policy may affect controls that agencies currently have in the procurement process. Agencies may find it difficult to relinquish these controls, making implementation of the policy difficult. Performance or functional specifications may be appropriate in certain areas where controls are not critical and when the innovative process will be enhanced. Another factor that may inhibit innovation is the requirement for uniformity in procurement policies and regulations. While uniformity may be a reasonable feature in most instances, it may lack the necessary flexibility to stimulate innovation.

Unfortunately, improving the time frame of the procurement process is not addressed in the Presidential initiatives, and long delays may adversely affect innovations which have a critical developmental time period.

The presidential initiatives indicate the designation of a senior official, but fail to specify modification or expansion of Federal organization to provide appropriate support in this area. It is also not clear from the Administration's initiatives if the intent of OMB Circular A–109, "Major Systems Acquisition" and OMB Circular A–76, "Policies for Acquiring Commercial or Industrial Products and Services Needed by the Government" will be effectively utilized and reformed to augment the innovation process.

As an example of congressional oversight of the procurement process, the House Committee on Government Operations currently reviews Federal ADP procurements meeting certain cost or size criteria. This type of congressional review of Federal procurement, while not extensive, permits a selective review of procurements which may promote innovations, but rarely provides the comprehensive oversight of the Federal procurement process that may be necessary to significantly stimulate industrial innovation. Consequently, providing incentives to stimulate innovation through the procurement process may require some new governmental approaches. For example, Congress could choose to consider the potential of requiring an early identification by departments and agencies of those procurements that may contribute to the development and implementation of innovative technologies and processes. The possibility of Congress requiring "innovation impact statements" in the Federal procurement process also may deserve some attention. Congressional consideration also could be given to the establishment of a viable Federal-wide forum or focus to promote innovation through the procurement process, and to the possibility of developing a Federal procurement clearinghouse to pinpoint potential innovations.

H. Improving Our Regulatory System

The three steps outlined by the President to foster innovation through regulatory improvement would allow industry to select and adopt technology to achieve performance standards; require the executive branch agencies to forecast concerns and priorities; and establish systems for expediting approval of new projects and processes. Few would argue with these initiatives; but overall, the President's position regarding the impact of regulations on innovations seems to ignore potential complementarity of two forces.

First, no explicit consideration is given to the role that regulation can have in stimulating innovation. To the extent that regulations reflect appropriate social goals, they can and often do serve to encourage innovations which can benefit not only society at large, but also industry. For example, the goal of the Clean Water Act for zero discharge of pollutants—which has often been decried as impossible—nevertheless may have been an important force in the development of water recycling technologies which frequently save money. Similarly, the Clean Air Act requirements for auto emission controls have led to technological developments permitting reductions in emissions that might never have been obtained from market place forces.

Second, the call for continuation of cost-impact analysis is a call for extending the present philosophy which leads to irresolvable conflicts about the costs of complying with environmental and health laws, and gives further legitimacy to demands for reduced regulation and the relaxation of standards. The reason is that cost-impact studies emphasize the adverse impact of applying end-of-the-pipe technologies to outdated and inefficient technologies, while ignoring the potential benefits of innovative changes, especially in process design. Focusing instead on cost-effectiveness studies—studies illustrating how established goals could be achieved at least cost—would have presented a positive approach to merging the multiple objectives of the Nation. For example, a cost-effectiveness study for pollution control in the steel industry would, or could, encompass various technologies, including direct reduction and continuous casting. Benefits would likely include significant energy savings, improved yield and less home scrap production, reduced pollution, reduced capital costs, increased potential for use of purchased scrap, and improved productivity.

In short, the President's recommendations—appropriate in themselves—are limited by the preconception that regulations and innovation are antagonistic, while, in fact, they can and should be examined in light of how they can complement each other—and in so doing contribute positively to other national goals as well.

Regulatory reform is a major oversight issue now before Congress. A number of environmental programs are included in this review, but typically the emphasis has been on how these programs delay new energy facilities and impact on the economy; their impact on innovation has generally been a secondary concern, although the need for innovative pollution control technologies has been the subject of some congressional investigations. Whether the President's report will increase the attention Congress gives to the environmental regulation-innovation issue remains to be seen.

I. Facilitating Labor-Management Adjustment to Technical Change

To achieve the objective of facilitating labor-management adjustment to technological change, the President has proposed the establishment of a national labor-technology forecasting system, supported by both labor and management, "to forecast technological change within specific industries and to assess the implications for labor of such change." As a result of such forecasts, labor and management, presumably via the collective-bargaining process, could provide for retraining and other adjustment activities.

A forecasting system does not guarantee that management will be fully willing to take the necessary steps to reduce or eliminate the initial adverse effects on workers; such programs would have to result from the collective-bargaining process. Also, technological forecasts for specific industries are sometimes difficult to achieve given the uncertainties of technological development and the introduction of new technology in some industries. Only if some agreement could be made as to the timing of the adoption of new technology would a forecasting system benefit labor and management. Finally, the majority of the work force is not unionized or covered by collective-bargaining agreements and some specific industries, like the apparel industry, are largely nonunionized. Consequently, provisions would have to be made to ensure that nonunionized workers also would benefit from the forecasting system to be supported by both (unionized) labor and management.

Congressional action on the President's initiative for facilitating labor/management adjustment to innovation most likely would be in the form of oversight. In the White House Fact Sheet accompanying his message on Industrial Innovation, it is stated that the President has directed the Secretaries of Labor and Commerce "to work jointly with labor and management to develop a national Labor-Technology Forecasting System." Congress could, during appropriations hearings, investigate the extent to which the system has been implemented and the role that management and labor (unionized and nonunionized) have played in the system's implementation.

J. Maintaining a Supportive Federal Climate

The President's initiatives in the area of "maintaining a supportive Federal climate" for innovation constitute explicit recognition that, in addition to direct intervention in innovation, the Federal Government has a role to play in maintaining a climate that is favorable to private sector innovation. The President's measures in this area include: (1) asking the Department of Commerce and the National Science Foundation to host a meeting of deans of business and engineering schools to stimulate improved curriculum development (mentioned only in the Fact Sheet which accompanied the President's message); (2) establishing a Federal award for technological innovation for companies in six areas of industrial activity; and (3) "charging the National Productivity Council with the continuing tasks of monitoring innovation, developing policies to encourage innovation and assisting the departments and agencies in implementing the policies announced today."

The third point is the only reference in the President's message to a possible focus for formulating national policy, and for coordinating the relevant programs of the several involved departments and agencies in the substantive areas of technological innovation mentioned throughout the message. It remains to be seen whether: (1) this potentially rather low-level commitment to policy formulation and program coordination may be a reflection of an administration view that the national problems associated with technological innovation can be addressed most effectively at the national level by a decentralized approach; or (2) whether it is an effective commitment of resources on the part of the administration for coming to grips with the innovation problem in an effective, comprehensive, and coordinated fashion at the highest policymaking levels of the Government.

In the 96th Congress, an Ad Hoc Task Force on Technological Innovation was established in the House, chaired by Rep. AuCoin. In the Senate, Sen. Cannon has announced that he has requested the formation of a similar task force. Depending upon the thrust, strength, and duration which the Administration's activities in the area of industrial innovation take in the future, Congress—including these two task forces and the several committees in each house involved in different aspects of innovation—may choose to expand its role in the Federal efforts to support industrial innovation as embodied in the President's initiatives. Based upon congressional and other views discussed in the last section of this paper, "Reactions to the President's Message," it now appears possible that the Congress will assume the leading Federal role in: (1) maintaining the visibility and momentum of Federal efforts in and (2) continuing to develop a comprehensive approach to improving the Nation's performance of industrial innovation. This would include consideration of legislation in several of the areas as discussed in this paper, as well as oversight of the several executive branch activities proposed and instituted by the President.

K. Tax Policy

Although changes in the tax laws were suggested frequently during the course of the domestic policy review, the President's message on industrial innovation contains no tax policy initiatives. Citing the budgetary and economic implications of changes in the tax code, the administration signaled that such proposals may be forthcoming after its review of economic policy for fiscal year 1981.

A wide range of tax options is available to stimulate innovation. Tax incentives may be used to reduce the costs of innovative activities. A tax credit for research and development expenses is one example of this approach. Another example is more favorable depreciation allowances for plant and equipment used in commercializing new products or production technologies. Other tax changes are advocated to enhance the innovative capabilities of small businesses. These proposals are often designed to aid new, high-technology companies in raising equity capital to finance their formation and expansion. Capital gains tax cuts and special treatment of income from small business stocks are examples of this approach.

General investment incentives are viewed as providing encouragement for industrial innovation. The faster firms expand their capital stock, the greater the demand for new and improved production techniques. More rapid depreciation policies, corporate tax rate reductions, a higher investment tax credit, and other business income tax changes are recommended in this context.

Controversy exists over the use of the tax code in providing incentives for innovation. Opponents of such measures question the responsiveness of R. & D. and investment expenditures to tax changes by citing the importance of more fundamental economic forces in such decisions. They also point to problems like the windfall that firms and individuals would realize, the added complexity of the tax code, and administrative burdens resulting from such tax incentives. Advocates of these policies highlight the alleged effectiveness of other tax incentives, such as the investment tax credit, and cite the minimal governmental involvement required when using the tax code to encourage industrial innovation.

The President may propose tax incentives for innovation in his budget message or, possibly, in a tax cut proposal. Independently, several tax measures have gained some support in Congress. Bills that would accelerate depreciation allowances for businesses have several cosponsors in each House. Tax credits for R. & D. expenses and tax incentives for small innovative companies have also been proposed and may be part of a broader tax bill, if one is enacted.

L. Reactions to the President's Message

Initial reactions to the President's message in the science policy and political press, in many cases, were disappointed or muted in tone.[6] The thrust of these reactions seems to be that the President's proposed measures are not sufficient to do the job of solving many of the perceived national problems in industrial innovations. For example, tax measures relating to innovation were not included—they are to be "evaluated" at the time the President considers his fiscal policies for fiscal year 1981. Likewise, concern was expressed that the proposed funding and programmatic efforts are too minimal to be effective. On the other hand, the President's proposed measures in regard to patent policy have been favorably received, in general, as being in line with legislation already in Congress.

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[6] See, for example, White House Innovation Study Falls Short. Chemical and Engineering News, v. 57, Nov. 5, 1979: 7–8; Stanfield, Rochelle L. Not Much Innovation Here. National Journal, v. 11, Nov. 10, 1979: 1901; Wade, Nicholas. Carter Plan to Spur Industrial Innovation. Science, v. 206, Nov. 16, 1979: 800–801; and Carey, William D. Stalking Innovation's Woes. Science, v. 206, Nov. 23, 1979: 889.

As to the magnitude of his measures, the President stated that the message represents only "an important first step" and "an early skirmish in what must be a continuing battle to maintain the technological strength of the American economy." In response to one critic, Stuart E. Eizenstat, Assistant to the President for Domestic Affairs and Policy, and Dr. Frank Press, Science and Technology Adviser to the President, stated that: [7]

The President's proposals reflect a sensitivity to the need to make many changes in a variety of areas. Moreover, many major changes improving our regulatory system, strengthening the patent system, clarifying antitrust policy, and encouraging innovation through normal federal procurement process—do not involve new federal expenditures. The implication that the output is insignificant because it involves few expenditures, ignores economic realities and the value of the president's many non-spending initiatives.

Perhaps a fair assessment of the likely impact of the President's message on industrial innovation was made by William Carey: [8]

On balance, the outcome of the Domestic Policy Review is a plus. Although it hardly improves the near-term prospects for regenerating innovation in the national economy, it is credible as far as it goes. If the early skirmish prefigures an escalated campaign to come to grips with the questions, there will be no cause to complain.

Reaction in the Congress to the President's message was swift. During hearings on industrial innovation jointly held by four committees,[9] about one hour after the President released his message, several of the Members expressed some criticism of one or more of its proposed measures. The general tone of this congressional criticism seemed to be "too little too late." [10]

Further congressional reactions were expressed during the Industrial Innovation Colloquy held in the House on December 13, 1979,[11] during which several Members, including Rep. AuCoin, Chairman of the Ad Hoc Task Force on Industrial Innovation; Rep. Fuqua, Chairman of the Committee on Science and Technology; and Rep. Brown (of California), Chairman of the Subcommittee on Science, Research, and Technology, expressed their views on, among other things, what Congress now must do in the area of industrial innovation. The general view of these Members seemed to be that Congress now must push ahead in its legislative programs related to industrial innovation in order to maintain the Federal momentum begun by the President's "first step."

In short, it appears that whatever its merits, and there are several, the President's message on industrial innovation fell short of expectations. It is still to be determined whether the Administration's measures will also fall short. Whatever happens in the executive branch, however, it is likely that the ball has been passed to the Congress to decide whether to play a leading role in continuing to develop a comprehensive Federal approach to improve the Nation's performance of industrial innovation.

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[7] Eizenstat, Stuart E. and Frank Press. The Innovation Battle. The Washington Post, Nov. 13, 1979: A 18.
[8] Op. cit.
[9] Senate Committee on Commerce, Science, and Technology and the Select Committee on Small Business; and the House Committees on Small Business and Science and Technology.
[10] See footnote 6.
[11] Industrial Innovation Colloquy. Remarks in the House. Congressional Record, v. 125, Dec. 13, 1979: H11982–H12005. [Daily Edition.]

III. Implications for the Congress

From the time of its announcement in May 1978, the executive branch Domestic Policy Review on Industrial Innovation was the focus of attention of the entire innovation community, public and private. Speculation about the President's decisions ended when he made his announcement on Industrial Innovation on October 31, 1979. The foregoing material comments upon and reviews the two major public aspects of this exercise, the inputs to the Department of Commerce by its Advisory Committees in its public meetings and final report, and the outputs from the Office of the President. What is not discussed are: (1) the publicly unavailable materials from the executive branch departments and agencies that were inputs to the study and (2) what went on within the Department of Commerce study and the reaction to that study within the White House and other executive office review agencies.

During the 17-month period that the domestic policy review was in process, many other studies were being conducted in the industrial sector and in academic institutions. There are several implications for the Congress.

First, of course, are the direct requests to Congress made by the President in his Message. Several actions are explicitly directed to the Congress and several others implicitly require congressional action, perhaps in another context than a direct response to the Industrial Innovation message.

Second, many expectations were generated in the many studies, particularly the Advisory Committee recommendations, that were not reflected in the President's Message. Clearly, the intensive participatory process of the DPR generated momentum for ideas that suddenly were left without a patron when the President did not reflect them in his Message. These groups may now be expected to turn to the Congress to seek action on their proposals in which they have invested so much time and effort and, in a few cases, emotional commitment.

Third, there are the pressures, however indirect and diffuse, from the many parallel conferences, studies, and articles in the media on the general subject of industrial innovation. For those items that were not reflected in the President's Message, it is reasonable to expect that overtures will be made to the Congress for initiatives in these areas.

The fourth implication for the Congress is that, independent of the recommendations of the President or of the external groups, an opportunity is presented by the plethora of information now available for the Congress to take independent initiatives and to exercise leadership in a variety of areas relating to industrial innovation.

One of the clearest messages of the material on Research and Innovation is that analyses of individual items of the innovation system are probably not required until more thoughtful, strategic, and holistic policy directions are set. In a sense, since the academic, industrial, and interest groups, agencies, and the President himself have spoken in this area, the ball seems clearly to be in the lap of Congress.

Appendix

Advisory Committee on Federal Policy on Industrial Innovation

Advisory Subcommittee on Economic and Trade Policy

William M. Agee, Chairman
Chairman, President and Chief Executive Officer, Bendix Corp.

Members:

Henry Duncumbe
Chief Economist
General Motors Corp.

John L. Gray
Partner-Attorney
Emans, Hurd, Kegler, & Ritter

N. Bruce Hannay
Vice President, Research and Patents
Bell Laboratories

Walter Hoadley
Executive Vice President
Bank of America

Richard Jenerette
Chairman
Donaldson Lufkin

Peter Johnson
President and Chief Executive Officer
Trus Joist

Charles M. Jones
Director of Planning
GTE Products Group

Eugene M. Lang
President
REFAC Technology Development Corp.

Robert N. Noyce
Chairman
INTEL Corp.

E. R. Stanhope
Group Vice President
A. E. Staley Manufacturing Co.

Richard A. Stuckey
Assistant Chief Economist
DuPont Corp.

W. Bruce Thomas
Executive Vice President
Accounting and Finance
United States Steel Corp.

Advisory Subcommittee on Environmental, Health, and Safety Regulations

Donald N. Frey, Chairman
Chairman, President and Chief Executive Officer, Bell & Howell, Chicago, Ill.

Members:

David Anderson
Manager, Environmental Quality Con.
Bethlehem, Steel
Bethlehem, Pa.

Howard Bauman
Vice President, Science and Technology
Pillsbury Co.
Minneapolis, Minn.

Warren G. Cutler
Director, Corporate Research
Whirlpool Corp.
Benton Harbor, Mich.

Julius Harwood
Director, Materials Science Laboratory
Ford Motor Co.
Deerborn, Mich.

Arnold Kossar
Vice President, Engineering
Curtiss-Wright
Woodridge, N.J.

Thomas Krotine
Vice President
Gould Laboratories
Rolling Meadows. Ill.

Joseph T. Ling
Staff Vice President
Environmental Engineering and Pollution Control
3M Co.
St. Paul, Minn.

George Lockwood
General Partner
Monterey Abalone Farms
Monterey, Calif.

James F. Magarahan
Vice President, Corporate Manufacturing
M. Lowenstein & Sons, Inc.
Lyman, S.C.

Gerhard J. Neumaier
President
Ecology & Environment, Inc.
Buffalo, N.Y.

Cornelius W. Pettinga
Executive Vice President
Eli Lilly & Co.
Indianapolis, Ind.

Harry J. Pratt
Director of Manufacturing Services
Borg-Warner Corp.
Chicago, Ill.

Frederic J. Rarig
Vice President
Rohm & Haas Co.
Philadelphia, Pa.

Richard B. Scudder
Chairman
Garden State Paper, Inc.
Saddlebrook, N.J.

Patrick H. Seay
Executive Director, Reg. Affairs
Johnson & Johnson
Fort Washington, Pa.

Marvin Stolberg
President
New England Nuclear
Boston, Mass.

David Swan
Vice President—Technology
Kennecott Copper
New York, N.Y.

Robert Snyder
Vice President, Tire Technology
Uniroyal Tire Co.
Detroit, Mich.

Peter E. Wrist
Vice President
The Mead Corp.
Dayton, Ohio

James F. Young
Vice President, Technical Resources
General Electric Co.
Fairfield, Conn.

Etcyl H. Blair
Vice President
Director, Health and Environmental Sciences
The Dow Chemical Co.
Midland, Mich.

Gerald D. Laubach
President
Pfizer, Inc.
New York, N.Y.

Advisory Subcommittee on Procurement and Direct Support of Research and Development

Thomas O. Paine, Cochairman, Procurement
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RESEARCH, INNOVATION, AND ECONOMIC CHANGE: POLICY OPTIONS FOR CONGRESSIONAL CONSIDERATION

By John M. Logsdon*

CONTENTS

Abstract

This report is the summary and analysis of a workshop discussing public policy options related to research, development, and innovation activities and the contributions of those activities to economic change. The discussions of the workshop and this report were organized around four thematic questions:

1. What would happen if no new policy initiatives related to research and innovation were adopted in the next several years, and existing trends continued in both Federal support of R&D and Federal policies for stimulation and regulation of innovation?
2. What do we know about the contribution of research and innovation to productivity growth and economic change?
3. Do we know enough about the process of innovation to design effective government interventions intended to stimulate that process?
4. What are the potential policy options for Congressional consideration? What information is required before such options can be fully assessed?

Among the themes stressed during the workshop discussion were:

1. The apparent decline in the vitality of U.S. technological infrastructure and the loss of an "innovative élan"; and
2. The lack of definitive knowledge about the relationships between investments in research and development and desirable economic change.

*Director, Graduate Program in Science, Technology, and Public Policy, George Washington University, Washington, D.C.

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Although the workshop discussions produced no consensus on specific policy options, the general sense of participants was that:

1. There was a need for both remedial and anticipatory policy actions in the research, development, and innovation areas; and
2. There is enough knowledge, given the risks of no action, on which to base policy choice.

Policy options identified in this report as meriting particular attention included:

1. Developing attitudes and mechanisms supportive of positive government-business relationships in the areas of civilian research and industrial innovation;
2. Examining the organizational structure of the Executive Branch, with respect to its ability to carry out the Federal role in those areas, including the support of basic and applied research for industrial application;
3. Identifying existing Federal policies and practices which act as barriers or deterrents to innovation, and where it is possible without compromising the primary objectives of those activities, modify them to remove or reduce their negative innovation impacts;
4. Lessening Congressional pressure (or at least correcting the perception of such pressure) for short-term evidence of the success of Federal actions in support of industrial innovation, including research support and support of demonstration projects; and
5. Developing incentives for labor and labor unions aimed at persuading them to accept, if not actively support, technological changes in the manufacturing and service sectors.

ACKNOWLEDGEMENTS

This report was prepared under a contract with the Joint Economic Committee of Congress. For his confidence in the ability of the Graduate Program in Science, Technology, and Public Policy of George Washington University to take on this task, I am thankful to Walter Hahn. Walter, a Senior Specialist in Science and Technology with the Congressional Research Service, is the Area Driector for the Research and Innovation Area Study of the Joint Economic Committee's Special Study on Economic Change. He and his colleagues, Mary Ellen Mogee and Richard Kaufman, have been consistently helpful to us in organizing the workshop upon which this report is based and in translating the results of that workshop into a produce useful to the Special Study. The Research Director of the SSEC, Dr. Charles Sheldon, added encouragement when we could most use it.

At George Washington University, Kathryn Swafford provided valuable assistance in early stages of organizing the December 1978 workshop on research, innovation, and economic change. Barbara Mitchell helped me in the final stages of workshop preparation and at the workshop itself, and her good cheer added a lot to the proceedings. Kim Kennedy bore the bulk of the burden of translating the tapes of the workshop into over 200 pages of verbatim transcripts, and typed the final report. I am sure she is glad to see this document ready

for delivery. All of these individuals deserve and have my wholehearted gratitude.

My thanks also go to the busy individuals who spent two days with us in December sharing their ideas on the research and innovation area. They came from a variety of backgrounds and organizations, and the diversity and quality of their ideas and insights made the workshop a stimulating experience. Each participant has had the opportunity to review his or her workshop comments as they have been transcribed and used in this report. The selection of which excerpts to use, however, was my responsibility. I also have been responsible for preparing the portions of the report which place the workshop proceedings in a broader context and give a particular interpretation to them. Thus, any mistakes or questionable analytical judgments should be attributed to me.

1. Introduction

This report is intended as a contribution to the Special Study on Economic Change (SSEC), currently being carried out under the direction of the Joint Economic Committee of Congress. That study was initiated in 1977, and its findings will be issued in 1980. The Special Study will be a comprehensive and future-oriented look at the total range of factors influencing, and influenced by, economic change. It's underlying thesis is that—

> economic, social, political, international, and technical conditions have changed, and are still changing markedly. . . . No country today seems able to provide full employment, stable prices, continued growth, and nonbeggar-thy-neighborliness, all at the same time.[1]

and that—

> in critical watershed periods in our economic history, like the present, we need to reexamine the bases upon which we formulate economic policy.[2]

In organizing the Special Study, the Joint Economic Committee recognized the important role of technological innovation in influencing change, and the equally strong influences on the research, development, and innovation enterprise coming from the operation of the economic system. Reflecting these relationships, the Special Study has given particular attention to issues related to research and innovation. This report is part of that effort.

The focus of this report is those potential policy options related to research, development, and innovation which appear to merit congressional consideration in the overall context of the Special Study on Economic Change. The time horizon of the Special Study concentrates on the midterm (15 to 30 years in the future), rather than on short-term remedial actions or on longer term future possibilities. This time frame is broad enough to encompass the future impacts on economic change of shifts in the technological innovation process. This report focuses on how to make those impacts socially desirable. Dr. Charles Sheldon, Research Director for the Special Study defined the goals of this report succinctly. He pointed out that what policymakers want from this kind of research effort is "consensus views and building

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[1] Representative Richard Bolling in Congressional Record, Oct. 12, 1978, p. H12757.
[2] Senator Jacob Javits in Congressional Record, Oct. 13, 1978, p. S18926.

blocks" on what is, and is not, known about a particular class of economic relationships, so that they can make policy choices "from at least a firm foundation about the state of knowledge." Given the general sense of a watershed point in U.S. economic history upon which the SSEC is premised, Sheldon said, "What we need today are new building blocks to replace some of the old ones." [3] The policy options identified and analyzed in this report may be such "building blocks," i.e. paths of action which, in combination, may channel the process of technological innovation in U.S. society toward that society's economic and social well-being.

2. Organization of the Report

The analysis in this report is based primarily on discussions on research and development, technological innovation, and economic change at a workship convened by the Graduate Program in Science, Technology, and Public Policy of The George Washington University in December 1978. Attendees at that workshop considered four thematic questions:

1. What would happen if no new policy initiatives related to research and innovation were adopted in the next several years, and existing trends continued in both Federal support of R&D and Federal policies for stimulation and regulation of innovation?
2. What do we know about the contribution of research and innovation to productivity growth and economic change?
3. Do we know enough about the process of innovation to design effective government interventions intended to stimulate that process?
4. What are the potential policy options for Congressional consideration? What information is required before such options can be fully asssesed?

Participants in the workshop included experts knowledgeable in all aspects of the research, development, and innovation processes, and government officials involved in the Special Study on Economic Change and in the concurrent executive branch review of industrial innovation. Participating [4a] were:

Barry Barrington—R&D Policies and Priorities Program, Office of Technology Assessment

William Boesman—Science Policy Research Division, Library of Congress

Edward Brenner—Association for Advancement of Invention and Innovation

Kenneth Brown—Program Analysis Division, General Accounting Office

Marvin Cetron—President, Forecasting International, Inc.

Osmund Fundingsland—Assistant Director, Program Analysis Division, General Accounting Office

Bela Gold—Professor of Industrial Economics, Case-Western Reserve University

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[3] Remarks by Dr. Charles Sheldon to Workshop on Research, Innovation, and Economic Change, Dec. 14, 1978 (from workshop transcript).

[4a] Affiliations of participants are at the time of the workshop and are given for information; participants spoke as individuals, not as representatives of their organization.

Walter Hahn—Senior Specialist in Science, Technology and Futures Research, Library of Congress (Director, Research and Innovation Area Study, SSEC)
William Hamilton—Director, Management and Technology Program, University of Pennsylvania
Richard Kaufman—General Counsel, Joint Economic Committee
Ron Konkel—General Electric Research and Development Center (on leave from Office of Management and Budget)
Carol Kitti—Division of Policy Research and Analysis, National Science Foundation
John Logsdon—Director, Graduate Program in Science, Technology and Public Policy, George Washington University
Norman McEachron—SRI International
Stephen Merrill—Subcommittee on Science, Technology, and Space, U.S. Senate
Sumner Myers—Director, Technology and Transportation Programs, Institute of Public Administration
Mary Ellen Mogee—Science Policy Research Division, Library of Congress
Henry Nau—Graduate Program in Science, Technology, and Public Policy, George Washington University
Martin Robbins—Director, Colorado Energy Research Institute
Albert Rubenstein—Department of Industrial and Management Science, Northwestern University
Theodore Schell—Special Assistant to the Assistant Secretary for Science and Technology, Department of Commerce
Theodore Schlie—Office of the Assistant Secretary for Science and Technology, Department of Commerce
Charles Sheldon—Research Director, Special Study on Economic Change (on leave as Chief, Science Policy Research Division, Library of Congress)
Robert Stern—The Conference Board

Sections 4–7 of this report consider each of the four thematic questions in order. Each section includes both a summary and analysis of the workshop discussion and verbatim excerpts from those discussions.[4b]

There are several reasons for combining specific excerpts from the workshop discussions with such summaries and analyses. The intent is to communicate to the reader the flavor and intensity of individual expert opinions, while at the same time providing a coherent synthesis of the views expressed at the workshop. The selected verbatim excerpts have been arranged in an order which provides maximum clarity and focus in the report, not necessarily in the order they were spoken. No footnotes or other forms of elucidation are used in the summary and analysis, also in order to achieve maximum clarity and focus.

3. Overview

Although the workshop ranged over many topics, several themes consistently appeared throughout the discussions as having particular importance to the SSEC. Identifying those themes at this point in the

[4b] Verbatim excerpts from the workshop discussion are attributed to the specific participant being quoted, and are indicated by black brackets.

report may help as the reader approaches the detailed discussions of subsequent sections.

Major areas of workshop discussion included:

1. The crucial importance of effective and positive government-business relationships in any attempt to understand what public policy options make sense with respect to Federal involvement in the processes of research and development and technological innovation. While recognizing that a primary responsibility of government is to act in the public interest with respect to the functioning of the U.S. economic system, the sense of the workshop was that the current mistrust and overt hostility that characterizes many of the dealings between government and business are barriers to developing productive public policies. Finding ways of improving the processes through which government and business interact was identified as perhaps the highest priority need over the next decade.

2. The decline in the vitality of technological infrastructure concerned many participants. With a few exceptions, there was a general agreement that government could play a constructive role in supporting applied research and development related to the scientific foundations of technology and to either industry-specific or sector-wide commercial utilization.

3. The state of knowledge about the relationship between investments in research and development and desirable economic change, is far from definitive, according to the participants. Analysts are not yet able to identify the precise casual relationship between particular R&D investments and specific economic changes, such as increases in productivity or industrial capacity, nor are they able to assure decisionmakers, which of a range of possible policy options will produce a particular desired result. Nevertheless, participants agreed that the relationship between levels of R&D activity and rate of economic growth was highly plausible, and that government action to maintain the vitality of the nation's R&D enterprise on the grounds of its eventual economic and social payoff was justified.

4. Although there was agreement on the continuing need for government support of research, including basic research, to maintain the knowledge base upon which technological innovation and resultant economic growth rests, participants thought that more technological capability exists (if not in the United States, at least on a global basis) than is now being utilized. There was agreement that government attention to removing barriers to technological innovation, most of which had to do with economic, regulatory and other policy uncertainties rather than with levels of R&D funding, was merited.

5. Of the midterm implications of technologically-induced economic change some participants thought that the impacts of technology on labor deserved particular attention. One concern was the willingness of labor unions to accept short-term adjustments resulting from the introduction of improvements in the manufacturing process due to technological innovation. Another more fundamental concern was that the traditional job-creating impact of the introduction of new technology may not occur in the next decade, and that a situation in which technological innovation does not lead to new job opportunities may not be politically acceptable to labor.

6. Some participants thought that government might do well to pay particular attention to technological innovation for quasi-public markets, i.e., markets in which there is competition among suppliers but in which governments (including state and local governments) either subsidize purchases or act as purchasers themselves. In these markets, it was felt, the likelihood of public policy success was greater than when governments became involved in commercial, private-sector activities.

7. An underpinning concern among most workshop participants was the sense that United States as a society had sustained a loss of its "innovative élan." There was no agreement on what the government role in restoring the vitality of the innovative process ought to be. Views ranged from substantial government intervention to a much more limited government role in industrial innovation. The notion was generally accepted by workshop participants that the current state of affairs is undesirable and that some changes are required to restore the vigorous technological base on which U.S. economic performance depends, particularly in the context of aggressive foreign competition.

4. Defining the Problem

An essential step in defining policy options for congressional consideration is a relatively clear and specific notion of the problems those policies are intended to remedy, or, more idealistically, the goals those policies are intended to achieve. In the United States, government action, in most instances, is reactive and remedial, moving away from problems rather than towards goals. Although the time horizon of the SSEC is long enough to accommodate specific midterm goals and objectives, it is useful to understand as clearly as possible the current problems which provide the sense that changes—some different objectives and new policies—may be required.

The sense that there are many problems related to the condition, operation, and results of the research and innovation enterprise in the United States has become pervasive in the past few years. Science Indicators 1976 sketched a picture of declining innovative capability in the United States.

> . . . Since 1963 the United States has spent a steadily declining percentage of its GNP on research and development, down from nearly 3 percent to 2.2 percent. Japan, West Germany, and the Soviet Union recorded significant growth in the proportion of their GNP devoted to R&D.
>
> Foreign patents in the United States increased 91 percent between 1966 and 1976 to the point where patents of foreign origin represent 35 percent of all U.S. patents and are distributed across a wide range of subjects. The United States now has a negative patent balance with both Germany and Japan.
>
> The United States' share of major technological innovations fell from 80 percent in the mid 1950's to 60 percent in the mid 1970's. In output per man hour, the U.S. productivity gain between 1960 and 1976 was smaller than that of Japan, Germany, Canada, France and Britain.[4c]

A Library of Congress report summarizing 1978 hearings on industrial innovation and its relation to the U.S. domestic economy and international trade competitiveness identifies the components of the current problem:[5]

[4c] Cited in Mary Ellen Mogee, "Industrial Innovation and Its Relation to the U.S. Domestic Economy and International Trade Competitiveness," Congressional Research Service, Library of Congress, Report No. 78–204SPR (mimeo), October 1978, p. CRS–2.

[5] Mogee, op. cit.

(a) funding for U.S. industrial R&D has for the past decade barely kept up with inflation; in particular, Federal funding for industrial R&D has decreased over this period;

(b) R&D funding levels are, in the judgment of most experts, related to the pace of industrial innovation which, in turn, is thought to be a key component of economic growth and international competitiveness. Thus, a slowdown in R&D spending is thought to be one source of poor economic performance;

(c) although precise measures are not available, many observers detect the decline in the U.S. capacity for industrial innovation which is predicted to follow a decline in R&D funding;

(d) not only the pace, but the nature of industrial innovation is problematic; innovation appears increasingly oriented toward short-term, incremental, defensive changes and away from long-term, growth-creating developments;

(e) the competitiveness of U.S. industry in the international economy appears to be declining, at least in terms of the balance of trade; one possible cause of this decline is the loss of comparative technological advantage vis-à-vis our economic competitors.

(f) a number of government policies in addition to direct funding of R&D can affect industrial innovation; the cumulative effect of current policies—which include tax policy, regulatory policy, import policies, price controls, antitrust policy, and patent policy—is purported to be negative with respect to the potential rate and direction of industrial innovation.

A diagnosis much like that sketched above was accepted by the White House as a basis for approving a major Domestic Policy Review of Industrial Innovation. In the memorandum authorizing the review, Presidential advisor Stuart Eizenstat noted:

> Industrial innovation is central to the economic well-being of the United States. Innovation provides a basis for economic growth and is thus intimately related to productivity, to inflation, to unemployment, and to the competitiveness of U.S. products both in domestic and world markets Efforts to enhance or improve innovation activity therefore may lead to an improved economic posture in the United States.
>
> Several observations underscore the need for increased Federal concern for the industrial innovation process:
>
> Indications that industry underinvests in innovation in terms of the ultimate benefits to the firm and society.
>
> Increased private-sector R&D emphasis in recent years on low-risk, short-term projects directed at incremental product changes, and decreased emphasis on the longer-term research that could lead to new products and processes.
>
> Declining international competitiveness of some segments of U.S. industry as reflected in: a growth rate for productivity in manufacturing industries that is lagging behind that of some nations; the increasing penetration of domestic markets by producers of intermediate technology and basic industrial goods; and a level of production technology in certain important industries (for example, coal mining and steel production) that lags behind that in other countries.
>
> Difficulties that small, high-technology firms encounter in obtaining venture capital.
>
> The changed direction of industrial innovation in recent time resulting from the diversion of corporate effort from developing new products to meeting other social goals.
>
> Although in the United States the development of new products or processes is left largely to the private sector Federal economic, tax, regulatory, procure-

ment, and foreign policy—as well as direct Federal support programs—have a profound impact upon the innovation process. Given the central role of innovation in economic development and the expressed concerns for the innovative process, Federal policy affecting industrial R&D and innovation must be carefully reconsidered.[6]

Participants in the workshop were asked to discuss the likely results if no new policy initiatives related to research and innovation were adopted within the next several years, and existing trends continue both in Federal support of R&D and Federal policies for stimulation of innovation and regulation of economic activity. The purpose of posing this question was to identify how much leverage policy actions in the research and innovation area might exert on the overall functioning of the economy. Some analysts working on science and technology claim that fundamental problems with the economy are susceptible to "technological fixes." Other analysts suggest that R&D policy can have important, but basically marginal, impacts on the health of the economy.

The workshop discussions were somewhat inconclusive on this point. Participants agreed it is the general economic climate rather than problems with technological innovation that are at the root of the current malaise, and that the United States is in the midst of important structural changes in the economy on which R&D and innovation has little leverage. This suggested that whatever policy activities the government might undertake within the next few years in the technology area would have little midterm effect on economic well-being. On the other hand, there seemed to be a general sense that the longer term vitality of the American economy was in important ways dependent on the health of the research and development system and the effective application of its results through the innovative process. Rather than problems in innovation being a cause of current economic conditions, the concern was that those conditions were having adverse effects on the levels of industrial R&D spending and on the operation of the innovation process. It was felt that those effects would in the longer term lead to undesirable economic and social consequences. Participants thought there ought to be a recognition of the need to decouple policy on research and innovation, which has its impacts in the mid to long term, from the short term fluctuations of the economy.

One particular worry among the wokshop participants was that only calculations of short term benefits were being applied to investment decisions with respect to using new technology.[7a]

[Gold. We have known for a long time about the inadequate degree of net capital formation as a proportion of net national income. Another problem to which much less attention has been given is that the capital formation we have has been buying decreasing amounts of capacity. The price of capital is rising. There has been some assumption that technology has offset this. In the industries that we have studied this is not so. In the steel industry, the capacity per dollar of investment has declined steadily for thirty years and is now slightly below the level that prevailed in 1900. What I am suggesting, therefore, is that when you talk about innovations you are talking not about

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[6] Stuart Eizenstat, "Issue Definition Memorandum: Federal Policy on Industrial Innovation." White House, May 9, 1978.

[7a] Verbatim excerpts from the workshop discussion are attributed to the specific participant being quoted, and are indicated by black brackets.

development of ideas, not laboratory exploration of possible movements ahead in the frontier. What you are talking about is what exactly is brought into functioning operation and is going to have an effect on markets, costs, employment, and things of this sort. If most of these can be applied only through the utilization of capital, it is not only a question of how much capital is available, it is also a question of how much capacity you get for it. One of the parallel problems to this that we see currently is the lage amount of liquidity in major corporations and the extent to which this is being used to buy up existing facilities and existing properties instead of being invested in the application of new technologies. New technologies are available across the board in almost all industries, if you look at the world set of availabilities instead of merely thinking domestically. The real problem is that economically these new technologies are not considered profitable enough in the shortrun. This is really the critical issue we find. Senior executives are saying. "Yes I understand, it will take me five years or six years to build this plant involving this new innovation." Do you know what the discount value of that is back to the present? If you use 15–18% discount rates after five years, such investments simply aren't going to pay. It is better to put the money in the commercial paper markets.

[Companies in many sectors tell us they have a whole shelf of technologically advantageous proposals in which it doesn't pay to invest under present conditions. It is not just a question of there not being enough capital available, it is not just a question of the interest rate, it is a question of a range of uncertainties.

[With respect to the steel industry specifically, we have had very little modernization in the industry, hardly enough to offset the progressive obsolescence of the marginal plants. Each of the efforts that are being made to add new capacity in the form of new facilities involve the adoption of Japanese technologies and the attempt to buy some of this technology and know-how from the Japanese because they have done it. We have not built a new plant in the United States for more than twelve years. We are losing the technological infrastructure that we used to have before, so not only are we not adding effectively to new capacity, we are losing ground with respect to the technological infrastructure. Finally, for the longer run, we are cutting back on the basic research which will develop the technology ten years down the road.

[Cetron. We have something which is happening which I call the Harvard Business School Syndrome. We have gotten ourselves, even in the high technology areas, to a position where all we have ended up doing is putting in people looking at the bottom line in terms of dollars, and dollars only.

[Myers. A lot of what happens in technology really does depend on the élan of people who are moving technologies forward. What seems to have happened over the past several years is that for various reasons, a lot of that spirit has been lost. I think the system is very definitely running down and I think we are in danger of losing our essential infrastructure. I don't see that infrastructure so much in terms of particular skills: I see it in terms of a particular kind of spirit that goes into moving things forward. It wasn't so many years ago that people who took the longer view instead of shorter ones were considered visionaries. We don't put very much value on such people anymore. Visionaries make big and very expensive mistakes, but in attempting to avoid mistakes I think we are going too far in the other direction. Instead of honoring people who accomplish things—I'm not just talking financially—we give Golden Fleece awards which really chill the system. If the Congress really wants to do something it should veto the Golden Fleece awards.

[Schlie. One trend many people see is an overmanagement of R&D. The research sponsored in universities is more concerned with getting the next government contract than with potential industrial applications. This relates to the higher perceived need for accountability in government today. Perhaps it can be analogously related to management in private industry that is always looking for the more sure short-term payoff as opposed to the more risky, longer term aspect of research. A second trend is from the more general support of research by government to more specific and concentrated research, particularly in the cancer and energy fields. A lot of industry that cannot directly relate to those two areas feel that this trend is adverse to their position in terms of government support for R&D. Another trend industry sees is increased uncertainties across the board: uncertainty of capital formation, uncertainty of regulatory requirements, uncertainty about inflation. I think that private industry would say those are the primary concerns.

[Robbins. Given the present climate for procurement, the way the Government spends its money, there is an intense process of selection and control which implies a degree of knowledge that does not exist, at least within the government. And that is an inherent dilemma. Anybody with a highly innnovative idea who tries to sell that idea to the Government needs 8–10 months to get a procurement through. We have a tremendously over-managed system because of the implication that anyone receiving government support has to be publicly accountable. The source of this problem goes back to Congress and pressure for premature evaluations. You enter into a research program and these are the words your supporting agency uses: "Give us a nugget that we can show a congressional committee so we can prove we are doing something good."]

Another set of concerns at the workshop related to U.S. competitiveness in the international economy. Much of the current discussion in the United States on the relationship between technological capability and balance of payment considerations, export policy, and other aspects of international trade appears to assume that if only current problems in the high technology area were removed the U.S. position in the world economy would be assured. Analysts are increasingly recognizing that the U.S. situation is one in which this country will face effective economic competition from technological equals in many product lines. The major policy issues relate to maintaining our ability to compete effectively, not how to regain our "natural" lead in the world economy. This competition will come not only from the other developed economies in Europe and Japan, but also from the rapidly industrializing "upper tier" developing countries such as Brazil, Mexico, and Korea. Developing policies which underpin U.S. long-run competitiveness in this kind of global economy was thought by workshop participants to be a challenging and crucial task.

[Boesman. There are really two dimensions to this problem and I know we are all aware of them. If Japan or Western Europe did not exist, we would still be worried about innovation and productivity. But the very fact that we are in a very tough competitive race in high technology and low technology products with Japan and Western Europe puts a whole different face on this. We really have a two-dimensional problem. We are not concerned with the absolutes here but with the relative relationships we have with these other countries. Just trying to create a better society is very different than trying to compete with some very competitive folks who are trying to beat your pants off.

[Nau. I don't think there is any real evidence, if you define specifically enough what you mean by research-intensive trade competition in the international system, that we are falling behind in the last decade or two. It is possible that we haven't had enough time to see trends which will set in or have begun to set in after the changes in the international economic system in the early seventies, especially the change in the monetary system. At this point, from OECD (Organization for Economic Cooperation and Development) trade data through 1977, looking at the three and four digit SIC (Standard Industrial Classification) level, it is pretty clear that the United States is holding its own in the research-intensive products.

[I am wondering whether or not in fact the problems in the high technology area are the same as in some other areas, such as automobiles. The capital turnover and labor questions aren't really problems of any great significance in the electronic sector, are they? And what are the reasons for the apparent decline of our innovative, competitive position in those areas? I would really like to press this question: what is our current knowledge about the extent to which considerations of capital and labor in fact apply across the board? Are we talking about some very different sectors here in which the international competitive position is very different? There is no doubt that we are losing our shirt in steel but I don't classify that as one of these research intensive areas.

[Gold. I am a little troubled by two or three assumptions being made. If we are really concerned with the national economy, why do we concentrate on what we call technology-intensive industries? What proportion of the economy do they account for? A small but significant improvement in the competitive position of steel and autombiles and the other large employment industries would have a tremendous impact on our economy. Also, I don't know what you mean by research-intensive economies. Japanese steel doesn't pour in here across the board. There are very important differences among the different products.

[Science and technology pervade all applications of technology. One of the major advantages that the Japanese have is in computerization. They have made enormous advances far beyond the United States. This is leading to the redesigning of plants and to the development of scales of operation quite different from those we can manage with our manning practices.]

Although the United States has become a mixed economy with private and public decisions interacting to influence the nature and direction of economic activity, there remains a sense that, compared to most other societies, we have built into our economic system a capacity for self-correction of problems without explicit policy intervention. The question was raised as to why self-correction appeared impossible to most workshop participants.

[Logsdon. Is the situation, in the context of the reality of the U.S. society, culture, government, and private sector relationships, addressable? Compared to most other societies we are confident of the self-correcting nature of our private sector, of the ability for self-interest, profit motivations, the other things that underpin the operations of the economy. Why is there no sense that those kinds of corrective mechanisms are going to operate in this condition? Why is there a sense that this is an area in which an essential corrective element is some significant form of government intervention that does not exist? Why, if we left things alone from the Government's point of view, would not the short time horizons get longer, and the capital investments adjust themselves? What is wrong with the underpinning ideology of government-industry relationships?

[Brown. I think a lot of the problems are blamed on government itself. All sorts of regulatory actions and environmental rules get in the way of R&D. Also, people see the problem not as America in isolation with the private enterprise system coming up with some kind of rate of growth, but rather America against the world consisting of other prosperous countries with other governments who are behind all R&D progress. It is the free enterprise system against the world; against a somewhat interfering national government in competition with, maybe not progressive, but aggressive foreign governments.

[Fundingsland. The most important factors seem to be the uncertainty in the economic outlook and the uncertainty in the regulatory environment, both of which the Government has more to do with than the private economy. I think industry is running nervous and will not self-correct until the Government, together with industry, works something out. The first point then is to really sharpen the focus on the planning. What should be the Government's role? Obviously, the Government's role is different whether it be a program that is for the nation, like national defense or space, or a long-time commercial venture too big, too high-risk, and too long-term for industry to undertake alone, like nuclear energy. It is very different for research and innovation strictly in the commercial realm, where industry could do it alone, if the policy environment is proper. It seems to me the focus on the Government's role and on how to stabilize the regulatory and economic outlook, are the three major factors that need examining.

[Brenner. My particular area of expertise is in the patent area and the area of protection of intellectual property. In my view, looking over the past 10–20 years, I see a decline in the protection system in the United States which, in effect, means a reduction in benefits to cost ratio. This drives our research more into short-term projects rather than long-term, more risky projects. In terms of the protection of intellectual property, things have been going downhill for the last twenty years. If you can't have some sort of protection of intellectual property over a period of time, you are just not going to get a good return on investment.]

As summarized in the above discussion, workshop participants agreed that there was room for improvement in government policies dealing with research and innovation, and that those improvements were crucial to the long-term health of the U.S. economy. A discussion of specific policy options which might be particularly attractive in this context and thus deserving the close attention of the SSEC followed. In order to identify such policy options, the participants turned their attention to the current state of knowledge upon which policy design might be based.

5. The State of Current Knowledge

Fundamental to the attention being given the research and innovative area within a study focused on economic change is the assumption that there are causal linkages between performing research and development, incorporating the results of R&D into the process of industrial innovation, and deriving increases in productivity and overall economic growth from such innovation. This assumption is widely shared by both policymakers and analysts. For example, President Carter, in a recent address noted, "economists estimate that advances in knowledge have accounted for three quarters of our own country's economic growth in this century" and "we need innovation . . . for new ideas in America are central not only to reducing our dependence on foreign oil, but also on our efforts to control inflation, to improve productivity of our workers, to protect our environment, and to ensure the prosperity of the American people." [7b] In summarizing the views of scholars examining the relationship between R&D and economic growth/productivity, the National Science Foundation said:

> . . . all available evidence indicates that R&D is an important contributor to economic growth and productivity. Research to date seeking to measure this relationship (at the level of the firm, the industry, and the whole economy) points in a single direction—the contribution of R&D to economic growth/productivity is positive, significant, and high.[8]

Included as Appendix A to this report is a brief paper which reviews the state of scholarly knowledge about relationships between R&D and economic growth. This review concludes that although research findings confirm the general sense of an important connection between research activity and desirable economic changes, those findings do not provide the type of knowledge upon which R&D discussions or economic policy can validly be based. The reasons for the lack of operational utility have been summarized by Willis Shapley:

> First, the horrendous complexity of the problem. Second, the absence of an adequate theoretical structure which reflects the realities of the present U.S. economy (much less any other, differently constituted economy) and the ways in which technological changes affect it Third, the difficulty or impossibility of getting the data needed—accurate data, current data, and data that are disaggregated in ways needed for meaningful analysis. Fourth, the conceptul and practical problems of finding ways to measure outputs of R&D other than by its costs or other inputs. Finally, the problem inherent in learning from experience: does the past really tell us about the future? Will studies of the effects of R&D and innovation on the economy in the 1960s and early 1970s help us deal with the changing economic situations of the late 1970s and early 1980s?[9]

[7b] Speech by President Jimmy Carter to annual meeting of National Academy of Sciences, Apr. 23, 1979.

[8] National Science Foundation, "Research and Development and Economic Growth/Productivity," 1972, p. 3.

[9] Willis Shapley, "Research and Development: Fiscal Year 1979" (American Association for the Advancement of Science, 1978), pp. 78–79.

Workshop participants recognized the weaknesses in theory, measurement techniques, and data availability that put limits on the ability of scholarly research to identify in concrete terms the contribution of research and innovation to increases in productivity, economic growth, and other elements of economic change. The result of those limitations is that there was limited confidence on the part of participants that the causal links between research and innovation and economic change have been demonstrated on a valid empirical basis.

[Robbins. Like everyone around this table, I can only intuitively accept the linkage, but I can't go any further than that. I don't think anybody can, although I'd hope that somebody could.

[Logsdon. I think that one of the responsibilities of professional economists and analysts vis-a-vis public officials is not to go before them and say that there are analytic proofs of the relationship, but rather to communicate why we, who professionally work in this area, accept this intuitively.

[Cetron. Instead of perpetuating the same old myths we have, and reinfecting each other with them, I think someone ought to take a look and try to get to the bottom line if they can. If not, say, "Look, we can't prove that these linkages exist but we feel intuitively that they do; it's a visceral feeling that we have."

[Schlie, I don't think we're so badly off in using the informed consensus, logic, and intuitive approach. It seems to me that many of the questions about establishing these linkages involve the empirical kind of evidence that economists use and have been trying to demonstrate. But I don't know if that kind of evidence is any more acceptable to people than is sound logic.]

Many of the reasons for the inability of economists and other analysts to provide definitive evidence on the technology-growth link are discussed in the paper included as Appendix A. Workshop participants seconded many of the points in that paper and added some additional factors which limit the power of analysis on this issue.

[Gold. One of the most puzzling features is that the work in this area at the macrolevel simply never touches ground with respect to the realities of the specific technological potentials in specific industries; yet these potentials are the basis for the decisionmaking which brings about the economic changes. I must confess that I have the gravest doubts about relevance of the average statistical findings concerning the average relationship over the last twenty years of R&D inputs and GNP or profitability. In my judgment, most of this is nonsense. It won't even stand up in comparing different firms within the same industry, much less among industries. The need is somehow to build a set of linkages between macrolevel analysis and really meaningful studies at the level where there are specific technologies, and where you may be able to see what the economic effects are in the form of new capacity, or better products, or less costly operating processes and things of this sort. The thing that worries me is that all of the literature can be divided into two parts: a whole series of macrostudies and a wide heterogeneity of detailed microstudies. I see no one who has effectively connected these.

[I can't emphasize too many times that the problems are different from industry to industry. I don't care how much we talk about R&D

and innovations in general; there isn't a general innovation process that we really understand. It's simply not true.

We have got to work at this problem of the interconnection between the high specificity of technology and R&D and general economic impacts. There is no way in which you are going to take a grab bag of individual case studies, work out some kind of an average, and somehow project that onto a macrolevel. It won't work. We need to ask different questions. What is the role of R&D in a wide range of industries, including agriculture? Few talk about agriculture as a high technology industry, yet we lead the world because there are a whole series of major developments in the technology of agriculture. The ratio of R&D people to the number of farmers looks very low. This suggests to me that we must develop better measures of what we mean by advanced technology. What is the relationship between what is done at the level of individual products and companies and the general balance of trade, net balance of imports, exports of technology licenses and factors like that? To what do we attribute even such levels of technological superiority as may appear in exchanges between the United States and others? What are they due to? Are they due to the basic research of thirty years ago? Are they due to the fact that they build new plants embodying the technology that we developed here but didn't use? I don't think you should infer that because we have an industry like electronics which seems to be associated with high technology, that superiority with respect to research performance and application of technology explains the fact that the industry has a favored position in the market. I don't think you can jump to that conclusion. There are a number of intermediate assumptions which trouble me a little bit and seem to warrant more careful examination.

Barrington. I think we're getting somewhere. We must understand that R&D is not the engine, it is not the driving force; it is just one of the instruments that management can call upon. Research and development have to interact with money, and people's decisions, and the skills of peope that are quite aside from R&D. Performing R&D is a long way from the marketplace.

Logsdon. The whole presumption of measures to stimulate more research, better research, or different research, is a presumption that somehow that activity has economic payoff. I think this discussion is suggestive that the evidence of that link is not yet in a form that would be acceptable to a scholarly journal. But does the existing evidence at the level of decisions on the part of the private sector or public policy suggest that indeed it is in the interest of society to have more research and more innovation if what we want is economic growth? Do we know enough to know that it is worth spending time and effort and money and policy capital on the part of the Government to push this area of activity, on the belief that it is going to have the payoff that we want? We certainly have been acting that way for a long time. Is it the kind of assumption that ought to be examined or left unexamined?

Cetron. There is no standard. For various industries there is some good information; for other industries there is not. What may be good for one industry is not good for another. For instance, we may need protection in certain areas and not in others. The answer is, there is no broad policy; it is almost industry-to-industry.

[Fundingsland. The input-output model that has been developed is too narrow. You have to look at other facets of the whole enterprise, such as effectiveness of communications, science and technology information services, and the way the whole educational system interacts.

[Nau. I don't see very much attention being given to the question of how does a multinational company manage innovation today as contrasted with 15 or 20 years ago. There is a question about the extent to which the product life cycle notion really applies any more. Capital sources are available in foreign markets today which may not have been there 15 or 20 years ago. How does a multinational, once it is established deal with innovation; how does it deal with commercialization of its product? The whole product life cycle notion told us something about how the multinational company got established and what role technology transfer played in that process. We don't have any really good studies of how, in fact, the question of commercialization is managed within the multinational company. There are many advantages, maybe greater advantages, to commercialize initially overseas rather than in this country, particularly given the increasing uncertainty in regulatory areas.

[Gold. The task of determining what the benefits of an innovation are is not as simple as it sounds. We try to eliminate the effect of price changes by making the idiotic assumption that all the inputs and all the outputs are qualitatively unchanged by an innovation. I know of no major technology which does not change the qualitative nature of inputs or of outputs or of both, but past studies assume that they are unchanged. What you are doing is eliminating a good part of the effect of technology every time you make this kind of assumption. It is extremely hard to determine the effects of a technological innovation in any kind of a complex situation involving simultaneous changes in other factors, some generated by the innovation and others attributable to other developments. Trying to disentangle these is something I have struggled with for a good many years without very much success.

[It is very hard to make an evaluation afterwards about what the effect of an innovation has been. It is impossible to disentangle it from all the other influences that are changing the level of capacity and output, utilization, the prices of materials, the product mix, and other kinds of things. If you cannot make a really decent evaluation after the fact, imagine how difficult it must be to make an evaluation before the fact. Now this does not mean that we shouldn't try to do it. What it means is that some of the measures that we economists are bringing to bear on this process carry too much of a hangover from the problems that economists worried about 50 years ago. We are not refining tools sufficiently to grasp the differential impact of innovation. We are unwilling to deal with these difficulties that we all talk about. We say our tools are better than nothing. This reminds me of the old man who walks down the street and one of the youngsters stops him and says, "Grandpa, I see you are wearing spectacles." He answers, "Yes, you know I am getting old." The youngster says, "But there are no lenses in them." The old man replies, "I know, but it is better than nothing."

[If you don't understand what R&D is intended to do, how can you measure what its effects are? Yet R&D is directed to a dozen different kinds of objectives. If industry is trying to overcome a shortage of some kind of material, and you look at how much this innovation expanded output, you are going to find nothing. I challenge you to pick out which of four or five men running around the track is the better runner until you know what distance they are trying to run. A third-rate sprinter will run twice as fast as a good miler.

[What we are doing is taking a general rubric, R&D, and we are using it to describe a wide range of different activities. I think it is of critical importance to learn to differentiate between R&D which has been devoted to trivial improvements in products, and R&D seeking to effect major improvements in basic processes or to develop new kinds of products. If you lump these two together you are going to get a completely misleading conception of what R&D promises to contribute to the American economy.

[Kitti. I don't think we know that much yet about what a lot of the data means; one example is the patent balance.

[Cetron. Another problem which is important is that the data we collect may mean little. Everyone has been collecting data on average income per capita; this has been something used for years and years. We have data going back to 1900's in this area. It doesn't mean anything today. What is meaningful is the difference between the lower decile and the upper decile. The bigger the spread, the more insecure the country is. What I am really saying is that much data is worse than garbage in, garbage out; it is garbage in, gospel out. Statistics are stamped by some government agency and we accept them as valid measures or indicators. In fact, it may be nothing but a bunch of poorly collected data.

[Nau. One characteristic of our society is competition. I think, given that fact, that there is no need to be afraid of information. I don't think we have to worry about one report being stamped with a particular good housekeeping seal, because there will be another report out pretty soon with another good housekeeping seal on it. It seems to me we want to encourage that sort of thing. Weak data gets weeded out in the process.

[Konkel. I think it is very healthy for the science policy people to be cautious about the validity of their data. Economists don't share the same kind of skepticism, although I remember Oskar Morgenstern wrote an interesting book about the accuracy of economic observations in which he made some very telling points about the economic statistics that everybody uses without blinking. There is growing recognition that unemployment statistics ought to be disaggregated and looked at much more carefully because people are making policy judgments that may not be appropriate. My assessment is that the science and technology people don't have all that much to be concerned about relative to other sources of data that people commonly use. The data you would get out of Science Indicators or out of NSF's Division of Science Resource Studies are a tremendous source of information, at least on the input end of the problem. If you compare that with data available is the Statistical Abstract or the Council of Economic Advisors' Report every year, I don't think it stacks up too badly. Measuring the outputs of R&D is a whole different issue, and we clearly need to try harder.]

Scholars are continuing to work on the various research issues just noted, but the problems are difficult and progress has been slow. One knowledgeable observer, George Eads (now a member of the Council of Economic Advisers), told a 1977 NSF colloquium, "I am not convinced we know much more today about these issues than we did in 1970." [10] Workshop participants seemed to agree with Eads' observation. If Eads is correct and if it is likely to be some time before definitive analytic evidence of the existence and character of the causal links between R&D and innovation, and between innovation and economic change is available, then policymakers are faced with a difficult, but not unusual, situation.

The scholarly evidence for these crucial linkages is plausible, but far from certain, particularly at a level of specificity useful for designing public policies. However, there is pressure on policymakers for action now. The problems in economic growth to which technological innovation might make important ameliorating contributions appear to be worsening. Policymakers cannot wait for conclusive analytic answers to the questions they pose on what the impacts of various options will be. They are forced to incorporate the results of analysis into an overall process of weighing interests, uncertainties, and conflicting objectives and demands, leading ultimately to a judgment on what should be done.

It is unlikely that, in the context of complex public problems, analysis can ever identify a uniquely preferable policy option, too many nonrational factors are integrated into a public policy decision. With respect to the issues under consideration here, it seems that the major contribution of scholarly knowledge to policy design is at a general level. As Richard Nelson and Sidney Winter suggest:

> The current dialogue regarding policy toward innovation rests on two premises. The first is that technological advance has been a powerful instrument of human progress in the past. The second is that we have the knowledge to guide that instrument toward high priority objectives in the future. The first premise is unquestionable, the second may be presumptuous. While all the attention recently given by politicians to scholars is flattering, we believe that the scholarly community has much less to say about appropriate policy toward innovation than many scholars like to believe. Prevailing theory of innovation has neither the breadth nor the strength to provide much guidance regarding the variables that are plausible to change or to predict with much confidence the effect of significant changes.[11]

The position taken by Nelson and Winter would probably not command universal agreement among scholars working in this area. Other scholars believe that our knowledge is beginning to be adequate for use in designing public policies in the research and innovation area, or at least in identifying those policy options which are more or less likely to achieve their intended results. Whether there is adequate knowledge for these purposes was the next topic of discussion.

6. Knowledge as a Basis for Policy Design

If the notion that there is a significant set of causal relationships between levels of R&D activity and the pace and direction of innova-

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[10] George Eads, "Achieving 'Appropriate' Levels of Investment in Technological Change: What Have We Learned?" in National Science Foundation, Relationships between R. & D. and Economic Growth/Productivity, Preliminary Papers for a Colloquium, 1977, p. D–4.

[11] Richard R. Nelson and Sidney G. Winter, "In Search of a Useful Theory of Innovation," Research Policy, vol. 6, No. 1 (January 1977), p. 38.

tion activity, and between innovative activity and desirable economic changes is accepted, then the logical next question is whether scholars and analysts have developed an adequate knowledge base for designing government policies intended to stimulate innovative activity in socially desirable ways. Workshop participants thought that in a few areas the rudiments of such a knowledge base were in existence, and that analysts could contribute usefully to policy design in this area. But there were two important caveats noted by participants.

[Gold. The fact of the matter is that not all innovation processes ought to be stimulated. Not all innovations ought to be adopted. There are many innovations that work for some companies or in some countries which don't make sense to others. One of the reasons that they are adopted is because the people are thinking about linkages between the innovation and their goals. They are saying something as obvious as "will it pay for us to adopt it?" If the conclusion is no, they don't adopt it.

[Merrill. For those of us who are charged with doing something, the crucial question is, "What effect will anything we do have on what other people will do?" This is much more crucial than the question. "Will what we propose stimulate innovation and that in turn contribute to the balance of trade in the long run?" Those of us who are charged with actually recommending something are primarily concerned with two things. One is, if we propose something, will it be supported? One of the crucial considerations in that respect is will it be supported by those who have studied this area? Or will it be scorned? The other is, if we propose something, what will the people to whom it is directed do with it? It seems to me that this is a much more immediate consideration. We take on with a great deal of faith the long run linkages that we have spent so much time talking about. That is certainly the case in regulation. What we need to know is, if we change the regulatory structure, process, laws, standards, how will it change the way people behave?]

Several workshop participants pointed out that the knowledge of which existing policies act as barriers to private sector discussions to innovate is greater than the available knowledge on which new policies are most likely to speed up the innovation process. They felt that priority ought to be given to identifying those existing policies and to modifying them in ways which remove or minimize their undesirable effects on innovation while preserving their ability to achieve the fundamental policy objectives. This position implies a need to broaden the context in which a variety of government policies, e.g. regulatory and antitrust policies, are proposed and evaluated to include their "innovation impact." Such comprehensive and multifaceted policy evaluations are not the norm in the Federal government. Perhaps the current emphasis on stimulating industrial innovation will result in including innovation-related considerations more frequently in the policy formulation and/or policy evaluation processes.

[Hamilton. I'd like to suggest, before we focus on what can be done to stimulate the process, that we realize that one thing we do know enough about is how past and current government activities present obstacles and limit our ability to innovate. Before we get heroic by trying to stimulate the innovation process, we should at least think about mechanisms that might limit further damage. Awareness and sensitivity about whether what is being done might impede the innovation process is every bit as important as what can be done to stimulate the process in a positive way.

[Stern. I like the idea that we are looking at the removal of barriers as contrasted with proactive intervention. I am very scared about governmental intervention by the executive branch, but something that scares me even more is intervention by the Congress. The thought of legislative initiatives to intervene in the innovative process at our current state of knowledge is extremely scary to me. Legislative initiatives to remove barriers that are detectable and where some sort of causality can be attached would be very constructive. The process of innovation is a very delicate process; the closest thing to me is the process of a sperm fertilizing an egg. The conditions under which that occurs are very, very special sets of conditions. There are many ways to foul up the process and there seem to be very few ways to help it. The best approach seems to be let nature take its course.

[The United States more and more seems to be on an island by itself trying to make a basically private enterprise system work. Do we really want to resort to the kinds of strategies by which Belgium, Italy, and other countries get their share of, for example, the steel market around the world? I'm not sure that those are desirable policies for the United States. If we go that route, we will be one of them. Do we want that? I think the great experiment that we have been doing for the last 200 years is to be different. To me the thing to do is to try to preserve a sense of freedom and individual initiative. I spent a little time in the last year on a U.S.-U.S.S.R. exchange team dealing with the management of R. & D. The more I learn about the Soviet Union, the happier I am that we are not trying to do it their way. That statement "Do we know enough about the process of innovation to design effective government intervention?" is a Soviet-type statement.

[Myers. I think there needs to be a distinction made between regulations per se and the objectives they seek to achieve, and the process through which regulations are developed, promulgated, and enforced and the uncertainties that arise from that process. I can't imagine that there's anything wrong with looking at our regulatory processes to make sure that they are as good as they can be, and that they interfere in the least manner possible. I am highly critical of the fact that there doesn't seem to be enough information.

[Logsdon. What kind of information ought to be generated to tell us what to do vis à vis the regulatory process?

[Myers. I would identify a number of problems which arose from the regulatory process, and then try to figure out whether elements of the regulatory process created those problems. This is a public administration problem, rather than an innovation problem. Then I would figure out how to fix those problems if they were fixable.

[Logsdon. What I have heard is that the Federal government, with respect to the innovation process, might do more to remove disincentives than to provide incentives. That has been the balance of the discussion. Should the priority, if one has to set priorities for federal actions vis à vis the innovation process, be the first to strip away the disincentives or to try to develop some new positive incentives?

[Rubenstein. Why do you have to choose? One man's incentive is another man's barrier. The supplier for the auto industry loves the auto emission and mileage regulations because they are now selling stuff they have been trying to push for 10 years. In one study, we looked at 32 cases in the supply industry; about 10 of them involved a project that was unacceptable until a regulation came through; all of a sudden it was acceptable.

[Logsdon. What you are saying is that any action has differential effects.

[Rubenstein. Almost all do. Why do we have to choose negative versus positive?

[McEachron. There is also an ambiguous effect; there are two effects of regulation. The first effect is that if a product runs into regulatory problems, there is a negative effect on the survival of that product. Interestingly enough, there is also benefit from regulation. If an innovation oriented toward meeting a regulatory problem exists, that innovation is much more likely to be commercially successful.]

A point made by Robert Stern in the workshop discussion just cited deserves underlining. Often in discussions about the potential ways for the U.S. Government to stimulate industrial innovation, the variety of policy instruments developed by other developed countries for this purpose are cited, with the suggestion that many of them are candidates for use in the U.S. context.[12] While mechanisms such as preproduction orders, innovation banks, special treatment for high-priority industrial sectors, and the like ought to be examined, Stern's rather conservative position ought to be considered in any such evaluation. He said, "I am not sure that those are desirable policies for the United States. If we go that route, we will be one of them. Do we want that? I think the great experiment that we have been doing for the last 200 years is to be different."

One area in which the Federal Government has assumed the leading role in U.S. society is the support of basic research. Participants noted that such support was an essential element in maintaining the reservoir of knowledge upon which the processes of applied research, development, and innovation draw. They felt that this was one policy area in which the Federal role was being carried out relatively well. Participants feared that increasing pressure for a more active Federal role in support of the innovation process and more emphasis on the applied end of the research spectrum might lead to a shift away from basic research support. Such a shift would be most undesirable because any increases in Federal support, particularly financial support, for industrial research should not come at the expense of basic research support.

In addition to the tangible downstream contributions of basic research, one participant noted that basic research support has "great image value. . . . A visible government commitment to basic research says a great deal about what government's attitude is toward the whole business of science and technology."

[Boesman. It seems to me that there has been a singular almost non-emphasis on basic research in this discussion. One of the things that

[12] One example is the article by J. Herbert Holloman and his associates, "Government and the Innovation Process," in Technology Review, May 1979.

the Federal government can do well is sponsor basic research. We haven't talked about things like university research problems and national labs (which are an enormous national resource). Let's not lose sight of this basic part of innovation process; the first step, if you will.

[Myers. It's not clear what the linkage is between basic research and technology, and technology and economic growth. The linkage, however, is plausible enough that many people think there is a connection. Putting aside for a moment what the real value of basic research might be, it has great image value. I think that a visible government commitment to basic research says a great deal about what government's attitude is towards the whole business of science and technology.

[Robbins. I can make a case for basic research, but I can also make a case against it by arguing that basic research training enforces a particular value system. These values place a pursuit of purity far higher than the pursuit of applied ends.

[Gold. One of the most interesting aspects of innovational activity in Japan is the tremendous emphasis on technological intelligence. I visited a trading company which doesn't manufacture anything. I said to them, "How do you keep up with new technological developments?" They said "Yes, that's a very important problem. We've only just become aware of it, so we only have a staff of forty people who do nothing else."

[In American companies, I have never found a company that has as many as 10 people who really are trying to keep track of what's happening in technology around the world. My point has to do with basic research. The imput into applied innovation doesn't necessarily come only from the basic research here, and shouldn't. The Japanese approach is, "We stand on the foreigner's shoulders." We ought to reciprocate a little bit. We don't have to reinvent everything. A lot of good work goes on all over the world. Our companies should be more aware of what these possibilities are. Government could encourage this kind of effort.]

Workshop discussions were representative of current disagreements within the community of scholars and policy analysts about the likely efficacy of various policy options such as:

1. Aggregating currently fragmented markets;
2. Support of research related to industrial technology in which research results are potentially useful to all firms within an industry or an industrial sector, rather along the kind of research support which the U.S. government provides in the agriculture sector; and
3. Further direct support of civilian-oriented R&D intended for eventual commercialization by the mission agencies of government.

Some analysts believe that there are opportunities for useful government initiatives intended to influence the innovation process in desirable ways. The efficacy of direct federal funding of civilian commercially-oriented R&D has recently come under increasing questioning, however, and federal policy has turned away from funding the end the R&D spectrum closest to commercialization. In each of these areas, there has been accumulated over the past decade or so a body of experience and analysis which might be the basis of policy design. As the following discussion suggests, however, in none of these areas has there developed a consensus among analysts about the desirability of new government interventions nor about the precise nature of an intervention which might be undertaken. The workshop discussion closely parallels the debate over new government initiatives among the policy community at large. Liberals believed that the possibilities of success in some limited areas justified some positive actions. Conservatives thought that there was insufficient basis for new activties. They felt that the most useful thing government might do is to reserve some policy actions(particularly those aimed at incorporating the concerns of human health and safety and protection of the natural environment) which have had apparently negative influences on the willingness of the private sector to innovate. No one, however, felt that there was an unequivocally strong case in support of any specific new policy course. All participants recognized the uncertainties inherent in the current, and likely future, state of knowledge in this area.

[Fundingsland. I think the Federal Government could do more to identify and help to resolve barriers to market aggregation for products aimed at improving the quality and efficiency of services provided by state and local governments and other public institutions. Private industry will shy away from investing its own R&D money in developments for those fragmented markets because they don't know how to cope with them. If there were some way to overcome provincial state and local government regulations and develop acceptable nationwide functional or performance standards with respect to things like the housing industry or police vehicles, we might get enough of a potential market to attract private investment. Perhaps the Federal Government can work with the States to overcome some of these local obstacles.

[Myers. This is a conventional idea that has never been borne out in practice. I would go a step further and say that the opposite has been proven to be true. The transactional and informational costs of market aggregation are getting to be so huge that the game is not worth the candle.

[Fundingsland. Aggregating the market has just not proven out historically. It is conventional wisdom because it makes so much sense. I am not suggesting that the Federal Government do market aggregation, but rather look at barriers that contain aggregation and try to remove some of those so that the private sector can find something tractable to deal with.

[Myers. The barriers are sort of inherent in the fragmentation of local governments. Local government actually has a good mechanism to get aggregation to happen. I have watched Public Technology, Inc. try it for years and it has produced absolutely zilch.

[Robbins. I want to compare the investment in energy the Department of Energy is making and the investment we made in space. The most interesting thing I found in looking back at NASA (National Aeronautics and Space Administration) in terms of its impact on technology was that NASA had a tradition that came out of the old NACA (National Advisory Committee on Aeronautics) days of pushing technologies because they felt they were needed in order to accomplish a mission. NASA moved a whole set of areas in material, electronics, telecommunications and a wide range of things, thereby removing stumbling blocks to specific innovations. The Department of Energy works way downstream on the innovation process. They do not bring any new technologies into being. If they have a materials problem, they go around it, or avoid it, or just kill the process off. They are not nurturing and supporting technologies through the very early critical stages where there is no investment because the investment opportunities are better elsewhere. That is one of the reasons the aerospace industry has done so well. The risk had been reduced; the uncertainty had been reduced. There was a climate for very rapid change.

What I am really getting at is that a market was created for new technology. It was a very rapidly changing market, not bureaucratized. Buyers of technology were willing to take great risks because they were independent in many ways. That kind of marketplace allowed a lot of people to move into it and to take high risks, even when the major corporations would not do it, because there was a certain amount of security since the Government funded it. Defense is probably a much better example than space. The entrepreneurship that occurred in whole sets of areas occurred because there was a market support.

Logsdon. Market support was there essentially for extremely political reasons that had little to do with the sense that it was an investment in the future in stimulating technologies. This raises a question for the future. Can we simulate in a major area, as we did in space, the environment that allowed this kind of development of the frontiers of particular areas that were necessary for carrying out the job? That has not happen with energy, and there is not that sense of purpose with the energy program.

Robbins. I think it is a management problem frankly. I think the public propensity to solve a problem disappears long before the problem disappears. There is a limited period of time in which things can happen. I think it is too late to get that kind of process underway in the energy areas; it has already become a bureaucratic, very rigidly controlled development process. One of the questions is, how do you manage new technology that the Government is investing large amounts of money in? If not energy, the next one coming along that has got a technological base to it. How do you manage that to maximize the payoff on the margin to the commercial economy? I think this society, given its political philosophy, is congenitally incapable of investing money directly in technology. Certainly, you could have gotten more by putting money into machine tools than by getting spin-off from NASA, but nobody is going to put public money into machine tools.

Gold. Researchers are now digging into more fundamental problems. The cost of dealing with these problems frequently reaches beyond the possible proprietary values to individual companies. We are seeking knowledge of basic materials and processes which reach far beyond what one company could capitalize on and exploit itself. To deal with problems like that takes enormous sums. Big commitments are involved. Above all, there is a big gap between exploring a phenomenon at the laboratory level and meeting the whole series of additional technical problems as you try to scale up to a level which would fit into the large scale operations of many of our industries.

There are many stages here, so there is a large subcommercial level of research and development that is needed. Companies are aware of this but do not undertake such research because it is not only risky, it is long-term and a very heavy absorber of resources. Even if a particular firm did such research and achieved a breakthrough it wouldn't get all of the benefits.

[What I am suggesting is that the sources of major technological advances now require a deeper exploration of scientific foundations. This takes a long time; it is risky; it takes a lot of money. This is an area where it may be necessary to turn to government because the values of any success in this area cannot be appropriated by any one individual corporation or some little group of them.

[Konkel. Where is the market failure? You have to get down to specific examples. I don't think you can deal with it in the abstract. I think that, in general, the reaction of the private sector would be that if the government gets in, not far behind would come controls and decisions on which particular technology ought to be researched. There could be all kinds of control problems that probably don't reflect the right kind of market orientation. An example of the difficulties that can be encountered is the space program where there is some very fine technology now available in the Landsat program. How do you get that program into the kind of mode where people are really using the data and developing widespread applications? It just is not at all clear how you do that. I wouldn't want to take that model and try to apply it elsewhere. How to make things happen in the real world—the real economy—getting entrepreneurs out there working and taking government-sponsored technology and doing traditional things that we let the private sector do, is just not at all clear.

[Anybody who suggests that there are specific gaps or market failures toward the applied end of the R&D spectrum which need to be addressed should bring forward their cases on specific merit.

[Myers. Right now, the government bureaucrats are absolutely incompetent to deal with a lot of these private market issues. They don't have to remain incompetent, but before I let them loose to do anything else they have to demonstrate their competence. They have an opportunity to do it in multibillion dollars worth of research and development now underway at the Department of Energy. Why, then, don't we let them demonstrate their competence, and if they do a good job there then we can turn them loose to do other things. Private industry does seem to think very often that the Government knows something that they don't. Witness what happened with Operation Breakthrough. Those housing innovations made no sense at all, yet the Government put a lot of funds in it, and some very smart individuals supported the program. The private sector, seeing this, participated and nearly lost their shirts.

[Kaufman. If government gets responses from the business community which are not based on good business judgment, but on things like images, stature, and the executive contradicting his engineers, what are the implications? Is this another set of obstacles the Government might encounter from time to time in trying to stimulate innovations: not getting good, prudent business judgments from its business partners?

[Robbins. Why should you expect private organizations to function any differently than any other organization would function? Why should you expect better information from business than from a Senate committee? There are organizational dynamics at work which determine the ways decisions are made. In the energy business there are an increasing number of large companies who have entered into the separate grant-related projects which have absolutely nothing to do with the life of the company. They are participating and making a profit doing government-funded research, but they aren't in the innovation business in those areas.

[Rubenstein. I think you've got to be a little bit careful about the question of nonprudent business. We could also call this behavior noneconomic rationality. The image business could be an extremely prudent business. The cost of money to business can be one-half of a point higher because a security analyst has rated the business B- instead of B as an investment. Now, prudent business sense is that if one can get the security analyst to raise a firm from B- to B it is going to save half a percent in interest. We have to be a little bit careful identifying economic rationality with prudent business. A lot of seemingly silly things are done in the way of prudent business that have a rationality that can be quite well defended.

[Myers. There are basically two kinds of categories of market risk. One is low market risk innovations; these are innovations that have to do with internal productivity improvement. If you make steel better and cheaper, the buyer couldn't care less how you make it or how you accomplish this. He's not buying your internal system; he's buying your steel. So the risks from the market point of view are very low. To the extent that the government can encourage innovations in that category, it should.

[The other category, of course, is high market risk innovations. And, here you've got two kinds. One is innovations for private markets. That's the kind of thing that DOE is doing now. Then you have another kind of a market which is a mixed or quasi-public market, like in transportation. There's a difference with respect to these two types of high-risk innovations. Government people don't know very much about private markets. They use the word "commercialization" in every other sentence and they talk about market research, but they really don't know what they're talking about. With respect to quasi-public markets, the Government is really a lot smarter, and it's learning; we learned from a lot of serious mistakes that UMTA (Urban Mass Transportation Administration).]

The basically positive outlook of most workshop participants was represented by the notions that government can learn from past experience in the research, development, and innovation area, and that there are no a priori reasons why government cannot take effective policy actions to stimulate technological innovation if adequate analysis precedes policy choice. There was no consensus among participants on which specific policy actions would increase the rate of innovation and channel it into productive directions, but there was a general sense that some improvements in government policy were necessary and could be accomplished. The following section reviews a number of such potential policy options, with an emphasis on those options requiring congressional action to be effective.

7. Potential Policy Options For Congressional Consideration

During the workship discussion a number of suggestions were made concerning potential policy actions which government might take and which some participants thought would influence the research and/or innovation processes in a positive manner. Table I organizes most of those suggestions in terms of some general classes of policy options. It contains suggestions not in the excerpts from the workshop discussion included earlier in this report. This table suggests the variety and range of policy actions which together might constitute something akin to a national innovation policy. If policymakers desire to influence the rate and direction of innovative activity, it may well be necessary to undertake almost all of these specific activities, and undertake them in a mutually reinforcing manner. A primary purpose of Table I is to suggest the complexity and holistic nature of future policymaking with regard to research, development, and innovation, if that policymaking is to achieve policy goals.

Table I.—*A national innovational policy: potential policy options for congressional consideration*

General policy proposals

Adopt, on an across-the-board basis as possible, a policy stance that innovation is an essential contributor to national welfare and that government will, through a variety of means, continue to encourage it.

Define the government role vis-à-vis private sector innovation in such a way that business can plan its activities with expectations of stable government action.

Work through a variety of processes and mechanisms toward a sense of mutual understanding and trust between government and business. The cooperative nature of research and innovation activity makes it a good candidate for such understanding.

Identify those aspects of regulatory policy which have a negative impact on growth-related innovation, and develop means for including an assessment of those negative impacts in the evaluation of proposed regulatory actions.

Remove barriers to innovation arising out of existing government policies in addition to regulatory policies when this can be done without compromising primary objectives of those policies.

Allow time needed for society to adjust to shifts in government policy before pronouncing those policies successes or failures.

Develop means to encourage labor and labor unions to accept labor-saving innovations.

Change depreciation rules so that investors can begin to depreciate large-scale projects involving innovative technology as soon as they are initiated.

Insist that foreign countries not subsidize competitors of U.S. business in ways that undercut the advantages to U.S. firms of incorporating innovations.

Government organization and management

Improve the regulatory process in ways which remove barriers to innovation.

Improve the management of the government share of innovation-related activities, particularly civilian R&D programs.

Orient federally funded R&D intended for eventual commercialization toward the marketplace as early as possible.

Increase communication and provide better mechanisms for interaction between performers of research and potential users of research results.

Use existing Federal programs of civilian R&D as laboratories for learning how best for government to work in cooperation with the private sector.

Lessen tendency toward overmanagement of federally funded R&D activities.

Decrease demands and pressure for short-term returns on government research investments.

Undertake demonstration projects for major innovations on a joint government-industry basis; at a minimum, permit industrial consortia to fund demonstration projects.

Evaluate mechanisms used by other countries to support civilian R&D and industrial innovation to analyze whether they can and should be adapted to the U.S. context.

Establish, on the basis of government-industry cooperation, a number of technology development centers for various industries.

Establish a research and development corporation or similar mechanism, with a base of Federal funds, to invest in innovations for which private capital is not available.

Include in any new policy initiative a monitoring process designed to provide effective and rapid feedback on policy impacts.

Funding options

Sustain Federal commitment to support of basic research.

Develop support mechanisms for research and development activities at the "subcommercial" level, particularly by pushing the development of promising technologies.

Provide targeted support in those areas in which significant improvements in technological capability are possible.

Target Federal R&D funding and/or other forms of support to specific industries, perhaps even to specific firms, when such assistance is judged to be in the public interest.

Nonfunding options

Act in cooperation with state and local governments to reduce market fragmentation and/or to remove barriers to market aggregation.

Provide more effective protection of intellectual property over a long enough period of time to permit innovators/entrepreneurs the opportunity to earn adequate return on their investments and inventions.

Recognize innovators through awards or other status-conferring actions; eliminate activities which deter innovation and risk-taking.

Research needs

Stimulate research which links macrolevel and microlevel studies on innovation in a common framework relevant to policy choice.

Develop better data and measures with respect to R&D activity in both public and private sectors, including particularly output indicators.

Miscellaneous

Limit access of economic competitors to potentially valuable scientific and technical information, particularly information developed using Federal funds.

Assist U.S. firms in their efforts to identify promising developments arising out of fundamental research in other countries, including encouraging more scientific and technological "intelligence" activities.

Develop training programs to increase the number of people with specific skills needed for industrial innovation.

Encourage efforts to use existing highly skilled technicians at or near retirement age to train their successors on an industry-wide basis.

Of this total set of suggested policy options, several appear to merit particular attention because:

1. They received the support of a substantial number of workshop participants; and
2. They are appropriate to the Special Study on Economic Change and to consideration by one or more congressional committees.

These options include:

(a) developing attitudes and mechanisms supportive of positive government-business relationships in the areas of civilian research and industrial innovation;

(b) examining the organizational structure of the executive branch, with respect to its ability to carry out the Federal role in those areas, including the support of basic and applied research for industrial application;

(c) identify existing Federal policies and practices which act as barriers or deterrents to innovation, and where it is possible without compromising the primary objectives of those activities, modify them to remove or reduce their negative innovation impacts.

(d) lessen congressional pressure (or at least correct the perception of such pressure) for short-term evidence of the success of Federal actions in support of industrial innovation, including research support and support of demonstration projects;

(e) develop incentives for labor and labor unions aimed at persuading them to accept, if not actively support, technological changes in the manufacturing and service sectors.

Each of these options is further illuminated in the following workshop excerpts:

[Gold. We must take a positive view of the relationship between business and government; something must be done about it. The most important single thing that Congress could possibly do is to try to generate some means of getting industry and government people together more often. If there are fights there are fights, but they must keep getting together and jointly move toward some common objective. This must be done, because the future of society and the economy depend upon it.

[Myers. From here on in the relationship between the public and private sectors is where it's at. We simply have to learn how government people and industry people can work in a public-private partnership to further, not just the innovation process, but practically everything.

[Robbins. I happen to be a great believer in process. I think the problem is really a process problem. The present process of government-industry relationships is obviously counterproductive. I personally believe meaningful collaboration under present laws and political and economic philosophies is impossible, given the existing process. However, opportunities do exist at the present time to deal with the process problems between the private and public sectors. We could select a major enterprise in which a higher degree of public-private interaction already exists to work on the process. The R&D and innovation enterprise is a logical choice.

[Logsdon. What you're saying is that we should find some way to develop an approach in this area which, while it looks like what you're doing is substance, is really aimed at developing a process of useful collaboration.

[Robbins. Well, I think process without product is meaningless. But, process is the main thing; it's the engaging in the process that will bring the end. I think the R&D enterprise is a very good one for this approach because it is a public-private contracting enterprise, where everyone's got a stake in it.

[The NASA experience was a very interesting experience in this context. Collaboration was based largely on NASA Administrator James Webb's ideas, which carried on for awhile after he left. They were very much dependent upon him and his driving force. I happen to believe there are only certain times in an enterprise when things can happen. There has to be a very turbulent environment, and points of rapid change for you to do things. Once the turbulence goes down, a process gets a little more rigidified. I think we're going into that kind of a turbulent environment in terms of the R&D enterprise and innovation. You might strike now and get lots of things to happen. NASA's collaboration with the private sector worked because NASA operated in a turbulent environment. I think that was more important than anything else. Webb could do whatever he wanted to do. NASA influenced the educational enterprise. It got into the way industry structured itself. NASA created a market for new technology that went crazy in terms of spawning entrepreneurs.

I'm not saying that's what we want to do. I'm just saying those kinds of things can happen in a turbulent environment. I think we have an opportunity to come up with an entirely new view of process with respect to public-private relationships in the R&D enterprise. I don't think NASA is what we want to create. I don't think DOD (Departmet of Defense) is what we want to create. I think it requires some real thinking out from the process point of view.

Schell. Maybe one of the very effective things that government can do is stop pretending that we know better than industry what their problem is. Even if we don't think it's going to matter, perhaps we ought to take some steps to promote a psychology that we're being responsive to an industry's needs, or understand their problems, or at least are willing to try to do some of the things industry suggests.

Hamilton. I think a government initiative has to be to establish mechanisms that deal with these kinds of process problems. I think there's a great opportunity, but also an enormous danger. Most industrial groups will say that they support the current Domestic Policy Review of Industrial Innovations. They are working very hard, but they wonder what will happen after their advice has been given. What happens in followup to that advisory effort can be a great help, or it can do great harm to the interactions between public and private sectors. I personally think that one of the mechanisms that ought to be looked at here is using the Department of Commerce as a continuing broker, as a linkage to the private sector. Commerce should continue to look at linking mechanisms, both in the managerial-technical interface and the public-private interface. It will take a lot to set this up. It will be controversial.

Gold. We now have a culture in which business assumes that anything the Government does has some hostile intent associated with it, Even when the Government does something favorable, there is a real tendency on the part of lawyers and all other people in the corporation to figure out what the catch is. This is a rational reaction because this is how industry interprets its experience over an extended period of years. To alter this reaction, to achieve a sense of at least reasonable mutual confidence, is going to take some considerable period of time. It is going to take a certain amount of reinforcing evidence. Whatever it is that Government does in this area, the reaction won't be immediate. It is going to be very careful and suspicious. This is not an irrational reaction on the basis of industry's past experience. I think that one of the most critical things we can do is to undertake a program—an extended program, a continuing program—in which Government makes some commitments and makes good on them.

Logsdon. One of the things that comes through from this discussion is that there's a kind of three-way relationship between the technical community, the business community, and Government. We have talked about training technical people to understand the nature of business, and vice versa. How can you inject into that process, as people begin to carve out careers in this area, an understanding of the relationship between the innovative activity in the private sector and Government so that there could be the kind of two-way communication flow that a lot of people have stressed as an essential element? The Domestic Policy Review has established this dialogue between people at the chief executive officer and senior corporate official level and high-level Government officials on an episodic basis. It seems to me that Congress might think about the flow of a number of relatively junior-to-middle level individuals in the area we're concerned with, Government and industry.

Hamilton. I find all of this talk about cooperative programs between industry and Government just "pie in the sky." There are so few incentives. In fact, there are massive disincentives, to bringing the two groups together. If you start a private sector career, you are a fool if you ever put a foot in Government, with the very rarest of exceptions. I think the same is true if you start a career in the public sector.

Konkel. I don't really sense this great polarization and distrust in my sabbatical in industry, coming from OMB (Office of Management and Budget). One thing I have become aware of is that my own attitudes sometimes are wrong. I think that people like me tend to listen too much to agency people. On a few occasions in doing my budget examining job I have had consultations with people in the private sector about specific program issues, but I have to say that there's a real uneasiness about "going outside of the Government" for technical or program advice when budget decisions are being made. Advisory committees can help, but then you have problems of obtaining timely responses to the right questions, which frequently are not asked by the agencies. We need to do better, but I am not sure how.

Logsdon. Is one problem the organization of the Federal Government in areas like basic research to support technological development, basic research related to infrastructure rather than related to specific missions? Should there be organizational entities within the Federal Government to provide the focus for the kind of communication process we've been talking about? Is there a case that can be cumulated out of a lot of the things which have been said, to create new organizational structures, new bureaucracies related to the innovative process and to the basic, applied, and development work that supports innovation?

Merrill. As far as organization and reorganization is concerned, there's a vast difference between shuffling boxes and deciding what that particular agency, whether new or existing, is going to do. If there were a new mission for Commerce, if you really decided you wanted Commerce or some agency to perform this task of basic and applied research for industrial application, some sort of reorganization might make sense.

Gold. Either in terms of achieving the benefits of increases in scale or achieving the benefits of a major technological advance, a large corporation in the United States is made extremely nervous by the possibilities of success. If you have success in a large scale enterprise, you're going to push smaller firms out of the way. That brings penalties or coercions, or at least threats from our governmental structure. More and more, the FTC (Federal Trade Commission) and other agencies in the Government have come to the notion that if there's any concentration in any industry, by definition that means an absence of competition and, therefore, technological innovation is prevented. I think that does sometimes happen. I think government ought to watch out to see that it doesn't happen. In almost every other country of the world, government has been pushing companies together and pushing for the economies of larger scale activities, but this approach would make the role of small business much more difficult. This is a problem that large companies in the United States worry about.

[Similarly, if you have a major breakthrough, you might get a judicial decision which says that your new technology must be available to smaller competitors. Larger companies have the funds which can be put into somewhat longer term, more risky projects, but why should they make this investment if the result is not going to be an extended competitive advantage? First, the financial people are telling private sector executives to evaluate innovations only from an accounting point of view; then you have the lawyers telling them that even worse than failure might be success.

[Gold. I think one of the things that the Government ought to do is to help subsidize, together with industry on a joint basis, a series of major centers of pre-commercial research for industries which have lagged technologically for an extended period and which involve large numbers of jobs—the equivalent of what it did to the land grant colleges in setting up experiment stations. I think we ought to have a series of such industrial technology development centers at a number of leading universities around the country. I think we ought to have centers of that sort covering a dozen of the major industries of the United States.

[Stern. The idea of starting experiment stations at universities dealing with a number of industries worries me because we don't know if it would work and it would take a lot of money to do it. We are not equipped to run that kind of program. We do not have any experience in it.

[Gold. There is a weakness in an argument that says let's not do anything that we haven't done. Agriculture never ran the experiment stations until they ran the experiment stations, and they didn't run the experiment stations very effectively when they started. They had to learn how to run them. At some stage, if the problem is serious enough, you take certain kinds of risks. I don't think that simply taking a hands-off attitude is going to solve some of the problems that we have talked about. The question then becomes: What do you consider doing?

[Stern. I am not suggesting a hands-off policy. I want to be sure I am understood. Let's be sure that we examine the barriers and the removal of them as forms of intervention just as much as the addition of new initiatives. I am trying to say that there is more payoff likely by the examination of what we have done to the system that skews it in the wrong direction, and that could be done away with, than there is of the injection of new interventions.

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[Myers. One of the things that Congress might do is to take the time pressure off some undertakings. Government-sponsored innovations for quasi-public markets tend to fail when the Congress puts too much pressure on getting nuggets out fast. That was certainly the case with the Morgantown PRT (Personal Rapid Transit). It was the case with the desalinization effort. It was the case in a lot of other things that people know about. There are more culprits in there besides Congress, that is for sure.

[Logsdon. I think the issue is that we are undertaking, in this society, a process of trying explicitly to stimulate and guide a process of innovation with an increasing amount of that stimulation coming out of a political environment. That means that there are going to be political considerations affecting it.

[Myers. I am not saying depoliticize the process. There are two ways of handling the problem. One is to soften the pressures by educating the Congress as to the realities of how much time it takes to get things done. The other is to educate Federal administrators on how to accommodate such pressures as these. It is not just an either/or situation.

[Robbins. Whether it is put there by Congress or not, the executive branch perceives pressure to produce. The result is premature evaluations and shifting objectives. There is hardly a program that has had a technological content that has not been stubject to that kind of shift and that kind of pressure. If the source of this pressure is not Congress then Congress should be doing something about the bureaucracy.

[McEachron. It appears that there are two kinds of R&D projects: those that are seriously launched towards commercialization, and those that are political actions intended to displace pressure for achieving something. One uses R&D as a symbol; the other, R&D as substance. We may very well choose to use R&D as a symbol, but if we do we are not going to get the kinds of commercialization results expected as if you pursued commercialization seriously. Congress, in its oversight role, should be asking, "Is there a consistent policy about communicating wtih the private sector in explicit ways?"

[Gold. One of the most serious threats of all is that labor isn't going to let society get the expected benefits of innovation. I think this is one of the things that Congress really has to address, and not in a coercive sense. We must develop some means to provide incentives to the labor unions, and to labor, to welcome technological change. The freedom to introduce technological change, and the resulting encouragement to management to try to generate technological change, is certainly worth any price you'd have to pay to have labor accept it. At present, we are eliminating one of the major sources of potential savings which is what innovations are concerned with.

[I would like to see Congress consider an arrangement whereby a firm could begin depreciating large-scale projects as soon as it began building them. The result would be that the average amount of investment on which the firm would have to keep earning a return would be very considerably reduced. If, for example, it took six to eight years to build a plant and the firm were allowed to depreciate this annually at some reasonable rate, by the time the plant came on stream the net investment still embodied would be reduced by almost half. This would very considerably reduce the amount of investment and therefore increase the expected rate of return. I don't see that there would by any great penalty from the tax point of view because, presumably, taxes and profits thereafter would be that much higher because there would be less investment to pay off and the firm would be paying the existing tax rate. This would have a very heavy effect on capital budgeting calculations in terms of the present value of projects of this kind.

[Rubenstein. We should stop looking for broad-based panacea type measures. In full accord with the precedent for funding other aspects of the society, we should look at a specific industry and even a specific firm. (If we can bail out specific firms which are in trouble, there's no reason why we can't identify certain firms which have important innovation capacities, and at least consider whatever help they need). Maybe we can extend that idea to training. Perhaps we can make not categorical programs but specifically-tailored programs, so if we need foundry technologists or machinists, we can take advantage of the generation of skilled people who are still alive, and whose brains are working even if they are retired. Maybe we could put them to work training other people.

[Kaufman. I think the burden is on the person who is advancing a new policy, or change, or any kind of proposal, to demonstrate some likelihood of success or improvement. The problem is that today Congress is responding to this set of issues in the same way it responds to claims made by other interest groups. You have the steel group, the exporters and the importers, the farm lobby, and a science and technology lobby who are arguing or bigger budgets and tax incentives and so on. None seem to provide assurance that anything Congress does is likely to improve any of the problems it is trying to deal with.

[Stern. The legislative branch should look at legislative initiatives that are coherent with what is going on in the executive branch. Let's not have the administration doing one thing and the Congress doing something else. I would think that there would be more to be gained in terms of the public interest, in terms of the needs of the country, by that understanding. I think some pretty good things have come out of this DPR (Domestic Policy Review) exercise already, I think more could come if business could build a relationship with Congress and Congress with business.]

8. Final Observations

Considerable further analysis will be required in order to assess fully any one of the policy options identified in this report. Such analysis is not attempted here, since the purpose of this report has been to delineate potential options, rather than to recommend specific courses of action.

If there is a single message that this report has attempted by communicate, it may have been stated as concisely as possible by Al Rubenstein—"We should stop looking for broad-based panacea type measures." Throughout the workshop the point was repeatedly made that problems and opportunities in the research and innovation area are different from sector to sector, industry to industry, perhaps even firm to firm. Public policies aimed at ameliorating these problems and seizing these opportunities are unlikely to be effective unless they match the specific needs of a particular situation. Although it is tempting to seek general solutions and comprehensive policies, in the research and innovation area the much more challenging task of formulating "micro-policy" is likely to have higher payoffs for society.

In order to undertake this task, analysts will be required to synthesize existing knowledge and to identify situations in which crucial understanding is lacking. Policymakers, as they must in all situations, will select among options for action without waiting for analytic certainty with respect to the results of their choices. Although there are important gaps in our knowledge about linkages among research, innovation and economic change, the general sense of the workshop was that sufficient understanding exists so that choices among policy options can be made intelligently.[13] Further, there was agreement that actions now seem to be necessary if undesirable trends in the research and innovation area are to be reversed. What gaps in knowledge do exist will not be closed in the near-term, and a posture which recommends no action until our knowledge base is complete is one of political and institutional "loss of nerve." Yet, as this report has demonstrated, there is no consensus among qualified scholars and policy analysts as to what specific actions ought to be taken.

What complicates the development of specific micropolicies is a sense that such policies while they must be designed to fit the needs of a particular situation in order to be effective, also have interactive effects on other innovation-oriented actions (and other policy objectives). This implies the need for links between the reasoning leading to the choice of a specific micropolicy and some overarching "macrotheory" of the innovation process. As has been mentioned several times in this report, no such holistic theory dealing with the innovation process as an interactive system has gained general acceptance. What is not certain is whether, in the absence of such a general theory which links the macrolevel and microlevel aspects of the innovation process, specific actions can be taken without substantial risk of undesirable interactive effects.

As mentioned frequently in this report, there has been a loss of "innovative élan" in U.S. industry. This loss might be generalized to include government as well. Both government and business seem to have adopted a play-it-safe attitude with respect to entrepreneurship and risk taking in areas of potentially great private and public return. The lack of an established analytic consensus or an agreed-upon theoretical foundation upon which to base policy choice provides a convenient rationale for inaction and low-risk undertakings. The current of thinking running through the workshop, however, was that the answer is a qualified "yes" to the question posed to workshop participants:

> Do we know enough about the process of innovation to design effective government innovation designed to stimulate that process?

If this report has communicated this generally positive sense that there are reasonable and potentially effective policy actions with respect to research, development, and innovation activities available for congressional consideration, then its purpose has been accomplished.

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[13] Many of the ideas in the next few paragraphs have been derived from Walter Hahn, and I want to acknowledge his contribution to shaping my thinking on these issues.

APPENDIX A. A CRITICAL SURVEY OF THE STATE OF KNOWLEDGE ABOUT RELATIONSHIPS BETWEEN R&D AND ECONOMIC GROWTH/PRODUCTIVITY [14]

1. INTRODUCTION

Although many analyses of the links between organized research and development (R&D) and economic growth have been carried out over the past two decades, scholars are still at a relatively early stage in the development of knowledge about those links. Twice within the past several years (in 1971 and 1977), the National Science Foundation has organized colloquia on the relationships between R&D and economic growth and productivity. At both colloquia, the leading students in the field concluded that:

> Investment in research, both public and private, has clearly been one of the major sources of growth in output per man in this century. It has been a good investment both in the sense that it yielded a positive rate of return, and in the sense that this rate of return has been as good and often better than the rate on other private and public investments.[15]
>
> Different studies using different sets of dates and different methodologies indicate a direct rate of return to R&D of about 25 to 30 percent, which is more than twice the rate of return on physical capital.[16]
>
> Although what we know about the relationship between R&D and economic growth/productivity is limited, all available evidence indicates that R&D is an important contributor to economic growth and productivity. Research of data seeking to measure this relationship (at the level of the firm, the industry, and the whole economy) points in a single direction—the contribution of R&D to economic growth/productivity is positive, significant, and high.[17]

Taken at face value, the finding that R&D is a significant contributor to economic change should be of major importance to both public and private decisionmakers as they concern themselves with the efficient allocation of scarce resources to the various inputs into the economy. But a cautionary note seems warranted. As two observers suggest:

> The current dialogue regarding policy toward innovation rests on two premises. The first is that technological advance has been a powerful instrument of human progress in the past. The second is that we have the knowledge to guide that instrument toward high priority objectives in the future. The first premise is unquestionable; the second may be presumptuous. While all the attention recently given by politicians to scholars is flattering, we believe that the scholarly community has much less to say about appropriate policy toward innovation than many scholars like to believe. Prevailing theory of innovation has neither the breadth nor the strength to provide much guidance regarding the variables that are plausible to change, or to predict with much confidence the effect of significant changes.[18]

This essay summarizes the existing state of knowledge with respect to the contribution of R&D to economic growth and increased productivity. It is not a comprehensive summary of the literature on this topic,[19] rather, its purpose is to give a sense of the major approaches to inquiry and the principal findings of scholars working in this field. The essay pays particular attention to the limited body of findings with respect to the differential impacts of publicly funded and privately funded R&D on various industrial sectors, as an example of the gap

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[14] This is a modified version of a paper originally prepared for Appropriate Technology International, Washington, D.C., by John M. Logsdon. The original paper was distributed to workshop participants.

[15] Zvi Griliches, "A Memorandum of Research and Growth" in National Science Foundation, "Research and Development and Economic Growth/Productivity," 1972, p. 47. (Hereafter called NSF 1972)

[16] M. Ishag Nadiri, "The Contribution of Research and Development to Economic Growth" in National Science Foundation, "Relationships Between R&D and Economic Growth/Productivity," Preliminary Papers for a Colloquium, 1977, p. B–17. (Hereafter called NSF 1977)

[17] NSF 1972, p. 3.

[18] Richard R. Nelson and Sidney G. Winter, "In Search of Useful Theory of Innovation." Research Policy, Vol. 6, No. 1 (January 1977), p. 38.

[19] The 1971 and 1977 NSF Colloquia provide such a comprehensive overview.

between the current state of knowledge and what would be policy-relevant. The essay suggests some of the reasons why the current body of knowledge provides few useful insights to policy makers as they attempt to select the policy instruments and approaches most likely to stimulate technology-based economic change.

2. Early Studies

The pioneering studies of the relationship between technological change and economic growth were carried out in the mid-1950's. Solow's paper on the contribution of technological change to the non-farm U.S. economy from 1909–1949 was typical of the approach used and the major findings in these early studies. Solow specified an aggregate production function in which the inputs were capital, labor, and time. He then used the term "technical change" as a "shorthand expression for any kind of shift in the production function." Thus, says Solow, "slowdowns, speedups, improvements in the education of the labor force, and all sorts of things will appear as technical change.'" Solow found that output per man-hour had doubled from 1909–1949, and that 87.5 percent of that increase could be attributed to the residual input he had called "technical change." [20]

The "crudeness" of equating technological change with whatever increase in output was unexplained by other inputs, was unsatisfactory to economists,[21] and a number of studies in the early sixties attempted to refine this approach by including more inputs which had been omitted in earlier research. For example, Denison's comprehensive 1962 study The Sources of Economic Growth resulted in a relatively low unexplained residual; Denison concluded that "advances in knowledge" were responsible for some 40 percent of total increase in national income per employed person during 1929–1952.[22]

Also beginning in the late 1950's. economists began to treat R&D explicitly as a third input into the production process, and to examine the statistical relationship between that input and some measure of increase in output, usually defined as an increase in "total factor productivity," [23] i.e., productivity of both labor and capital inputs. These studies were cast at the level of a specific innovation, a firm, an industry, or a large sector of the economy. The findings of these studies all suggested that there was a strong association between the level of R&D input and productivity growth. For example, the combined work of Kendrick and Terleckyj led to the conclusion that an industry's rate of growth of total factor productivity was related in a statistically significant way to various measures of R&D intensity.[24] Griliches found that the rate of return from agricultural R&D between 1937–1951 was 35 to 175 percent.[25] Mansfield suggested a 40 percent return in the petroleum industry and a 30 percent return in the chemical industry,[26] while Minasian found the return in the chemical industry to be closer to 50 percent.[27]

3. More Recent Studies

Two more recent studies exemplify the manner in which economists are attempting to refine the basic production function approach. Leonard's 1971 study of the contribution of research intensity to various output measures for sixteen industries performing almost all U.S. manufacturing was the first to investigate the differential impact of private and public R&D spending. Leonard's data included R&D spending for 1957–63 and rates of growth for the 1956–1968 period. He found that private R&D spending was strongly related to various growth measures, but when the research intensity variable included "Federal R&D funds, correlations with growth rates fall, usually below significance." However, "by eliminating two industries receiving five-sixths of Federal funds—aircraft

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[20] R. M. Solow, "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, vol. 39, No. 3 (August 1957), pp. 312, 320.
[21] Edwin Mansfield, in NSF 1972, p. A–22.
[22] Edward F. Denison, "The Sources of Economic Growth in the United States" (New York: Committee for Economic Development, 1962.)
[23] Edwin Mansfield, "Industrial Research and Technological Innovation" (New York: W. W. Norton & Co., Inc. 1968.)
[24] Nestor E. Terleckyj, "Sources of Productivity Advance. A Pilot Study of Manufacturing Industries, 1899–1953," Ph. D. dissertation, Columbia University, 1960.
[25] Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," The American Economic Review, Vol. LIV, No. 6, (December 1964).
[26] Edwin Mansfield, "Rates of Return from Industrial Research and Development," The American Economic Review, Vol. LV, No. 2 (May 1965) pp. 310–322.
[27] Jora R. Minasian, "The Economics of Research and Development," The Rate and Direction of Inventive Activity (Princeton: Princeton University Press, 1962), and "Research and Development, Production Functions, and Rates of Return," The American Economic Review Vol. LIX, No. 2, (May 1969), pp. 80–85.

and missiles and electrical equipment—significance emerges between Federal R&D intensity and growth rates." [28] Leonard interpreted his findings as showing that the concentration of Federal research funds in the space and defense areas had negative impacts on the economy, rather than that Federal R&D support in general was economically unproductive.

It had been clear that, in addition to direct returns to a firm from R&D performed by that firm or industry, such R&D had indirect benefits accruing to those who purchased the goods or services incorporating its results. For example, an R&D-intensive product such as a computer certainly produces gains in productivity for industries such as banking which make increasing use of computers. Attempts to measure this indirect return on R&D were initiated by Brown and Conrad in a 1967 paper [29] and applied in a 1974 analysis of both manufacturing and non-manufacturing industries by Terleckyj. This study dealt with three dichotomous variables:

1. Public R&D vs. private R&D;
2. Direct returns vs. indirect returns; and
3. Manufacturing industries vs. non-manufacturing industries.

Terleckyj found that the direct rate of return for all manufacturing R&D was 10 percent and the indirect return, 45 percent. However, when he separated spending on manufacturing R&D into government and private sources, he found no return, either direct or indirect, for government-funded research, and a much higher return (30 percent direct and 80 percent indirect) for privately funded R&D. For non-manufacturing industries, Terleckyj found "erratic" results, but estimated a zero direct rate of return for these industries (which in fact perform very little R&D) but a 187 percent indirect rate of return.[30]

Other studies, such as those conducted by Griliches [31] and Nadiri and Bitros,[32] also obtained results suggesting substantial rates of return from R&D investments. In summarizing these studies, Mansfield suggests that—

> All of the studies based on econometric production functions in the 1970's seem to have obtained results which are consistent with earlier studies. . . . In addition, however, they have gone beyond earlier studies in a number of ways. First, they have extended the coverage of the analysis to almost 1,000 manufacturing firms. Second, they have taken a much more adequate account of inter-industry technology flows. Third, they have tried to distinguish between returns from privately financed and federally financed R&D. . . .
>
> One central finding of particular significance is that these studies, like the earlier ones . . . , indicate that the marginal rate of return from investment in R&D is very high.[33]

Other analysts, however, suggest that the mainstream of studies to date may be leading down a blind alley. Nelson and Winter suggest that studies based on a production function are "useful and provocative but have not cut very deep" and that "the breadth and strength of the production function framework is inherently limited." They suggest that "it is necessary to study in some considerable detail the processes involved and the ways in which institutions support and mold these processes." [34]

Such a micro-approach, based on case studies of the innovation process, has increasingly been followed in recent years. A representative study is that of 17 innovations conducted by Mansfield and his associates. Using company records and interviews with innovating firms and their competitors as well as published information (as contrasted with the aggregate data used in econometric studies),

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[28] William N. Leonard, "Research and Development in Industrial Growth," Journal of Political Economy, (March-April, 1971), p. 232.

[29] Murray Brown and Alfred H. Conrad, "The Influence of Research and Education on CES Production Relations," The Theory and Empirical Analysis of Production, ed. Murray Brown, Studies in Income and Wealth, No. 31 (National Bureau of Economic Research, 1967).

[30] Nestor E. Terleckyj, "Effects of R. & D. on the Productivity Growth of Industries: An Exploratory Study" (Washington, D.C.: National Planning Association, 1974).

[31] Zvi Griliches, "Returns to Research and Development Expenditures in the Private Sector," Conference on Research in Income and Wealth, Nov. 13–14, 1975 (National Bureau of Economic Research, 1975).

[32] M. Ishag Nadiri and George Bitros, "Research and Development Expenditure and Labor Productivity," eds. John Kendrick and Beatrice Vaccara (National Bureau of Economic Research, 1977).

[33] Edwin Mansfield, "Research and Development, Productivity Change, and Public Policy," in NSF 1977, p. A–5.

[34] Nelson and Winter, pp. 44, 46.

they found that the median private rate of return was 25 percent and the median social rate of return was 55 percent.[35] In another study, Mansfield's team used quite detailed data on a single large firm from 1960–72, and found the average rate of return from this firm's total investment in innovative activities to be 19 percent.[36]

At the opposite end of the aggregation scale, Chase Econometrics Associates in 1976 performed a study which attempted, at the level of the total U.S. economy, to measure the impact of NASA R&D spending on the rate of productivity growth. Chase used a multiple regression equation to estimate the rate of technological progress in the U.S. economy, treating NASA R&D spending and other R&D spending as separate independent variables. The rate of return on NASA R&D was found to be 43 percent. The Chase study also used macroeconomic simulations to estimate the impact on various economic indices of increased productivity resulting from NASA R&D spending. Among the results (all of which indicated positive impacts) was that a sustained $1 billion increase in NASA spending for the 1975–1984 period would increase constant-dollar GNP by $23 billion by 1984.[37]

A General Accounting Office analysis of the Chase Econometrics Associates study suggested that the report "does not prove convincingly that the benefits are as large as stated," and characterized the study as "exploratory research." GAO criticized the study's "sensitivity to small changes in methodology" which led to "major changes in the results," GAO also was somewhat skeptical that the correlation between NASA R&D spending and changes in productivity were a true cause-and-effect relationship, and suggested to NASA that a more micro-economic approach to evaluating the impact of NASA's R&D would provide more useful information to policymakers.[38]

4. Government vs. Private R&D

An example of how the results of existing studies must be interpreted with care, particularly as a basis for current policy discussions, is the treatment of the differential impact of government-financed and industry-financed R&D on productivity increase. Terleckyj told the 1977 NSF symposium that the findings of studies which have examined this question are consistent with the hypothesis "that government-financed R&D either has no productivity returns or has returns significantly lower than privately-financed R&D." [39] Upon close inspection, the studies to which Terleckyj refers contain qualifications which severely limit the generality of his hypothesis and limit it in ways which make it not very relevant to policy issues with respect to civilian-orented R&D.

One of the first analysts to ask whether the source of R&D fundng made a difference in growth was Leonard. He looked at research input during 1957–1963 and found that "despite the larger amount of government funds entering this research, company R&D funds enjoyed the strongest positive association with industrial growth." Leonard then divided the sixteen industry groups for which he had data into two categories: fourteen groups in which Federal funds accounted for less than half of total R&D expenditures, and two groups—aircraft and missiles and electrical equipment—in which Federal funds were 89 percent and 67 percent, respectively, of total R&D expenditures. For the fourteen "commercially-oriented" groups (Leonard's terms), the average Federal share of R&D expenditures was 24 percent. Leonard found that for these fourteen commercially-oriented industry groups, "research intensity based both on Federal expenditures and manpower ratios evidenced a strong association with seven of eight measures of industrial growth." (but not productivity). Leonard interprets his results as showing that "it is the disproportionate allocation of Federal R&D funds to two industries that impairs the contribution of these funds to growth." [40]

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[35] Edwin Mansfield, "Technology and Technological Change," Economic Analysis and the Multinational Enterprise, ed. J. Dunning (London: George Allen and Unwin, 1977).

[36] Edwin Mansfield, J. Rapoport, A. Romeo, E. Villani, S. Wagner, and F. Husic, "The Production and Application of New Industrial Technology" (New York: W. W. Norton, 1977).

[37] Chase Econometrics Associates, "The Economic Impact of NASA R. & D. Spending," 1976.

[38] General Accounting Office, "NASA Report May Overstate the Economic Benefits of Research and Development Spending," 1977.

[39] Nestor E. Terleckyj, "Recent Findings Regarding the Contribution of Industrial R. & D to Economic Growth," in NSF 1977, pp. C–6, C–7.

[40] Leonard, pp. 245–251.

Griliches reaches similar conclusions. He notes that the two industries with the largest Federal involvement in financing of R&D (in 1963) yield the lowest rate of return, but comments that—

> It is interesting that we have stumbled on this impact of federally-financed R&D in the interpretation of our results rather than in the econometric analysis itself. In our regressions we were unable to discover any direct evidence of the superiority of company financed R&D as against federally-financed R&D in affecting the growth in productivity. It may be that within any company a dollar is a dollar, irrespective of the source of financing, but that in these two specific industries the externalities created by the large federally financed R&D investments and the constraints on the appropriability of the result of research that may have been associated with such investments, have driven down the realized private rate of return from R&D significantly below its prevailing rate in other industries.[41]

Griliches does suggest that, at the level of an industry rather than a firm, "a concentration of federally-supported R&D in one area may lead to an overall decline in the rate of return to all R&D there." [42]

Terleckyj's own research also includes distinctions that qualify his conclusions about the efficiency of Federal R&D spending. In his 1974 study, he divides government R&D "between the contract research undertaken clearly in support of the effectiveness (productivity) of specific governmental programs (mostly in the field of national defense and space exploration), on one hand, and government financed research clearly undertaken for the purpose of enhancing productivity of the given industry, on the other." Terleckyj's study used 1958 R&D data, and in 1958 "the only major case where government financed R&D was directed at productivity of an industry was agriculture;" therefore, Terleckyj included government agriculture R&D funding with industry R&D input, not with government R&D input. Given this treatment of his data, it is not surprising that Terleckyj found almost tautologically that government-financed R&D has no positive effect on productivity growth of the industry in which it was conducted, and that the evidence of indirect productivity effects was unclear.[43]

Neither Terleckyj's study nor others reviewed in the essay provide much insight into the likely impact on economic growth of recent Federal R&D funding in the civilian sector. They use data from the late 1950's and early 1960's, when defense and space research took most of Federal R&D funds. The output measures used in these studies do not capture the impacts of Federal support of biomedical research or other activities which have their impact on the quality rather than the quantity of economic activity. The limitations on the use of these studies as a basis for current policymaking are suggestive of the general caution which should be applied in relating the results of this body of literature to policy choice.

5. Conclusion: The Limits of Current Knowledge

Most economists would agree that the body of findings from the representative studies reviewed above confirm the intuitive notion that technological change is a driving force behind economic growth and increases in productivity for most of this century. These studies have also shown that both the private and social rates of return to investments in R&D are generally high, and there is some indication that the rates of return are different for government-financed and industry-financed R&D. But what else can be learned from this body of work? Specifically, can research results be used by policy-makers and decision-makers interested in maximizing returns of R&D investments, both in the United States and in other countries? Do we know anything, on the basis of these studies, except that R&D inputs and increases in productivity are statistically, and probably causally, related?

Unfortunately, the answer to these questions seems to be *no*. Willis Shapley suggests that "it seems fair to say that the economic studies up to now, and the conclusions that can be drawn from them, do not go very far toward answering

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[41] Griliches, 1975, pp. 6–2, 6–3.

[42] Zvi Griliches, "Issues in Assessing the Contribution of Research and Development to Productivity Growth," Charles River Associates, Inc., 1978, p. 32.

[43] Terleckyj, 1974, pp. 21–28.

the key questions. . . . The studies . . . have not yet provided much on which to base either R&D decisions or economic policy." [44] Bela Gold thinks that "most of the generalizations about the efficacy of technological innovations and of increasing allocations to R&D programs, which have gained widespread acceptance, are based on shaky foundations. Because major isues of resources allocations and of related policy development are involved, it seems unduly hazardous to be guided by comforting, but essentially untested and highly vulnerable, generalizations." [45] Even Edwin Mansfield, although he suggests that "available analytical techniques are sufficiently powerful to permit significant improvements in the state of the art" with respect to providing satisfactory answers to major questions confronting policymakers, finds existing studies "frail reeds on which to base policy conclusions." [46]

Why this pessimism with respect to the operational utility of research results? Shapley provides some general answers:

> First, the horrendous complexity of the problem. Second the absence of an adequate theoretical structure which reflects the realities of the present U.S. economy (much less any other, differently constituted, economy) and the ways in which technological changes effect it. Third, the difficulty or impossibility of getting the data needed—accurate data, current data, and data that are disaggregated in ways needed for meaningful analysis. Fourth, the conceptual and practical problems of finding ways to measure outputs of R&D other than by its cost or other inputs. Finally, the problem inherent in learning from experience: does the past really tell us about the future? Will studies of the effects of R&D and innovation on the economy in the 1960s and early 1970s help us deal with the changing economic situations of the late 1970s and early 1980s? [47]

Each of these problem areas deserves more detailed discussion than is possible within the limits of this essay, but the following paragraphs suggest some of the key barriers to arriving at operationally useful conclusions.

Technological innovations affect economic relationships: "(1) through a variety of intermediate linkages; (2) within a network of interacting pressures; (3) covering an expanding horizon of operations; (4) over extended periods of time; and (5) accompanied by a variety of independent but concurrent developments." [48] Existing studies, particularly those based on a production function model, capture none of this complexity. The various inputs into the technical change process are mutually interacting, as are the outputs, and demand and supply are mutually interdependent and confounded with other influences.[49] There is an increasing body of microeconomic studies dealing with topics such as the nature of the research and development and innovation processes, the sources of innovations, factors associated with successful project selection and implementation, etc. While in principle these more microscopic studies could complement the generality of econometric analyses and thus capture the texture and complexity of the means through which R&D inputs are translated into increases in productivity, such has not been the case. A primary reason is the lack of any unifying theoretical framework within which various studies might be carried out and their results aggregated. As it is, there simply is no valid way of comparing the results of studies using different concepts, different assumptions, and widely varying data bases.

There has been particular criticism of the use of a production function as the theoretical model for understanding the relationship between R&D inputs and productivity increase. Nelson and Winter believe that "the breadth and strength of the production function framework is inherently limited," since it contains "at best a rudimentary characterization of process and relevant institutional structure." [50]

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[44] Willis H. Shapley, "Research and Development Fiscal Year 1979: AAAS Report III," 1978, p. 78.

[45] Bela Gold, "Research, Technological Change, and Economic Analysis: A Critical Evaluation of Prevailing Approaches," The Quarterly Review of Economics and Business, Vol. 17, No. 1 (Spring 1977), pp. 24–25.

[46] Edwin Mansfield in NSF 1977, pp. A–15, A–8.

[47] Shapley, pp. 78–79.

[48] Gold, p. 21.

[49] Nelson and Winter, p. 45.

[50] Nelson and Winter, p. 46.

Gold is even more critical, suggesting that the use of the production function model is "rooted in the implicit, though rarely expressed, fundamental assumption that the important economic effects of all technological innovations are essentially similar and already well-known, except in respect to their specific magnitudes in given situations" and that "resulting findings of average input-output relationships, average time lags between inputs and benefits, and average rates of profitability seem quite devoid of significance, however, when compared with the extraordinary diversity of the actual undertakings camouflaged by the simple aggregative input and output measures used." [51]

Griliches, who has used a production function model as the basis for much of his work in this area, speaks of the "conceptual poverty of our models" and calls for "realism as to what the production function approach can and cannot accomplish." [52] There is a growing realization that this approach must be incorporated in some broader theoretical structure if research is to provide answers to the kinds of questions being asked by policymakers. Unfortunately other approaches to understanding the R&D/productivity connection have also not yet reached an adequate level of theoretical understanding. As noted earlier, there have been a number of studies conducted on various "microscopic" aspects of the innovation process, but these studies have "proceded within disjoint theoretical frameworks" and their results cannot be linked with the results at a higher level of aggregation coming from the studies using the production function approach. As a result, "our knowledge is Balkanized." [53] At the highest level of generality, the Chase Econometrics study has been strongly criticized not only for its conclusions with respect to the economic impact of NASA spending, but also for the weaknesses in theory, methodology, and definition of key variables and relationships which made the study's results subject to question.[54]

Even if adequate theoretical structure were available, there are major problems in operationalizing variables, in measuring them, and in having available adequate data. Griliches notes that "difficult problems exist in the measurement of output in the government and service sectors. . . . Unfortunately the more research and development intensive is an industry, the more likely is its output to be subject to such measurement problems." [55] Nadiri concludes his 1977 NSF paper with the plea that "most importantly, there is an urgent need for better data to test the hypothesis suggested on the role of R&D in the growth process." [56] Current data do not allow analysts to distinguish between the differential effects on output of basic research, applied research, and development, and "more generally between the results of the more fundamental long-term industrial research and the short-term oriented R&D." [57] Furthermore, past and current studies are based on data fom the 1960's and early 1970's, and there have been enough shifts both in the distribution of R&D allocations (especially by government) and in the growth rates of the economy to call into question the utility of older data as a basis for reaching conclusions about current relationships.

The various criticisms of the results of economic studies to date suggest why George Eads (now a member of the Council of Economic Advisers) could say in 1977 that "I'm not convinced we know much more today about these issues than we did in 1970." Eads is among those interested in this area of research who are calling for a "fundamental shift in emphasis" if researchers are to learn much that is useful about how government can effectively and appropriately influence the level of innovation.[58] Eads echoes the call of Nelson and Winter for a much richer theoretical foundation for the microeconomic analysis of the sources of productivity growth. In order to obtain useful knowledge about R&D decisions, it may be necessary to understand corporate decisionmaking in general, and to do so at the level of specific industries, perhaps even specific firms. It is suggested that only on the basis of such knowledge, can effective government interventions into the innovation process, including the contributions to that process of R&D, be designed.

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[51] Gold, pp. 8, 17.
[52] Griliches, 1978, pp. 37–38.
[53] Nelson and Winter, p. 47.
[54] GAO, pp. 6–8.
[55] Griliches, 1978, p. 3.
[56] Nadiri, in NSF 1977, p. B–27.
[57] Terleckyj, 1974, p. C–16.
[58] George C. Eads, "Achieving 'Appropriate' Levels of Investment in Technological Change: What Have We Learned?' in NSF 1977, pp. D–4, D–13.

If one accepts this line of reasoning, then how is the body of knowledge reviewed in this essay to be evaluated? Certainly this research and its basic findings with respect to the strong influence of technological innovation on the processes of economic growth have provided the justification for government's interest in assuring the adequacy of current and future R&D investments. Refining these studies on the basis of more adequate measures of inputs and outputs, more up-to-date data, and comparisons with relationships in other economies than that of the United States will continue to be a useful undertaking. Such refinements will enable other analysts and policymakers to have a clearer sense of what the overall pattern of relationships is, even if they cannot go directly from those patterns to specific conclusions on how to influence the input-output relationships in desired ways. Thus work at the aggregate level is one part of a broader attack on the problems of understanding the economics of technological change. Only through such a combined approach, using a theoretical framework that allows for synthesis of the results from studies at various levels of generality, is it likely that economists can provide valid and useful answers to questions of R&D investments, the process of technological innovation, and the appropriate role of technology in the future of societies at all stages of development.

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Technical Advance and Economic Growth: Present Problems and Policy Issues

RICHARD R. NELSON

The OECD Then and Now: What is Different?

To sketch, from the perspective of somewhat heterodox economist, some of the key issues of science and technology policy that face the countries of the Organization for Economic Cooperation and Development and particularly the United States, and that call for new thinking over the coming decades, my point of departure will be to describe a number of important differences between the OECD countries as they are now, and as they were during the heyday of rapid growth. To some extent, these differences are describable in terms of the economic troubles of the 1970s—slow productivity growth, high inflation rates, high levels of unemployment, and balance of payments stress—compared with the more salutary economic conditions earlier. But such a recounting provides a biased and somewhat superficial view of what has changed in the OECD countries over the past quarter-century.

Compared with the 1950s, virtually all of the OECD countries now have much higher real per-capita incomes, and levels of real private consumption have risen dramatically. Virtually all of the OECD countries have taken major steps to place a floor under individual and family standards of living, and to protect people to a significantly greater extent than before from the vicissitudes of labor-market conditions and personal infirmities or bad luck. As a striking example, a large fraction of the currently unemployed in many of the OECD countries have had their income losses largely buffered by unemployment payments. In addition to providing income maintenance, the modern welfare states have vastly increased the range of goods and services that are public provided or

Richard R. Nelson is a Professor at the Institution for Social and Policy Studies and Professor of Economics at Yale University.

which are largely financed through government rather than private budgets. Almost all of the OECD countries now have some form of national health insurance. Most provide housing and other services at subsidized rates for individuals and families on low incomes.

As a consequence jointly of generally higher average living standards, and of the greater role of governments in influencing income distribution and resource allocation, the old traditional sectors of agriculture, mining, and traditional public utilities now account for a significantly smaller fraction of the work force than they did 25 years ago. Private and public services, in particular, now absorb a significantly larger fraction of the work force.

The growing governmental role in resource allocation and income distribution has been accompanied by increased regulation of private economic activity. Environmental and energy regulation, and job safety and product-attribute regulation, are now forces that business must heed in deciding what they are to do. These forces constrain and complicate the answer to the question of what can be produced and sold at a profit.

I propose that the various developments sketched above are linked together. They reflect growing affluence and an associated rise in the relative importance of values that the rapidly growing, basically market-guided economies of the 1950s and early 1960s were slighting or punishing. I will argue shortly that the described developments have something to do with the observed economic malaise of the past half-dozen years. But they need to be recognized in their own right. Even if the economic sailing had remained smooth, the developments would pose challenges to science and technology policies. Given the rough sailing we have experienced, the challenges are compounded.

The Economic Slowdown

The last half dozen years look particularly bad in comparison with the era of rapid growth that marked the previous decades. But to put that perception in context, it is important to recognize that economic progress during the 1950s and 1960s was unusually rapid by historical standards. In order to understand what has gone wrong recently, it is useful to consider what went right earlier.

Certainly the initial conditions set the stage for rapid growth. Almost all of the OECD countries had experienced economic stagnation during the thirties. Many of them experienced devastating physical losses during World War II. Thus, all of the nations came out of the war with a perception of large unmet needs for private and public goods, of capital shortages, and of a large shelf of unused technical advances that had accrued over the years of depression and war. This was a situation virtually guaranteeing a high rate of return on investment and rapid productivity growth as capital expanded, if aggregate demand and supply could be kept in relative balance.

In view of contemporary tendencies to depreciate economics as a science and economists as policy advisers, I would remark that, throughout the post-World War II period, economists have advocated, and governments have gone along with, active demand-management policies and, until recently, these policies have worked. Aggregate demand growth was not permitted to fall behind growth of the capacity of economics to produce goods and services. Until recently, unemployment was generally kept low, and inflationary forces generally under control. It well may be, of course, that the initial conditions made the balancing task of fiscal and monetary policy relatively easy. Because of high investment demand, governments did not have to act directly as demand stimulators and did not have to run budget deficits to that objective. High investment and rapid productivity growth meant that pressures in the high-employment economy toward sharply rising wages did not have to result in high inflation rates. In any case, until recently, macroeconomic policies worked.

The era of rapid productivity growth was marked not only by high investment rates, but by significant changes in the allocation of labor across sectors and industries. While high levels of employment were preserved generally throughout the period, in some industries employment fell rapidly. But with overall demand high and growing, and overall unemployment low, labor mobility was facilitated. In the first part of the rapid-growth era, the dominant shift was largely out of agriculture into manufacturing, transport, public utilities, and services. Toward the end of the era, the dominant shift was into services.

While all of the OECD countries entered the post-war era with a catalogue of technologies that had been developed during the 1930s and the war years and that had not been incorporated into practice, this source of productivity growth with high returns to capital sooner or later had to run out. But research and development spending in all of the OECD countries was strikingly larger during the rapid-growth era than in earlier periods. If the initial conditions set the stage for rapid growth and made the task of demand-management policies relatively easy, the significant technical advance experienced during the postwar period continued these salutary conditions. The rate of return on investment continued to be high (although late in the 1960s there were some signs of decline). Investment rates continued to be high, and labor continued to move from low to high productivity sectors. By the late 1960s, the bulk of employment growth was no longer in manufacturing but in the services.

This shift into the services can be explained by two related but different factors. First, in the late 1960s, private demands for both manufacturing and services seem to have been relatively price-inelastic. While sectors experiencing rapid productivity growth did experience relative price declines, since demands were relatively insensitive to price, resources shifted out of industries with rapid productivity growth, principally manufacturing, and moved into those experiencing slower productivity growth, in the case of services. The second factor was a significant increase in governmental spending on services, particularly education and health, but including as well a wide range of welfare services.

By the late 1960s, there were some indications of trouble on the horizon. The United States began experiencing both inflation and balance-of-payments problems, and there is evidence of deceleration of productivity growth at about that time. One prominent study of that early deceleration in productivity growth accounts for much of it in terms of a shifting allocation of resources. There was little evidence of any sector-by-sector or industry-by-industry decrease in rates of productivity growth. The inflationary problems of the United States were contagious and some of the basic problems that were leading to inflation in the United States obtained as well in Europe. By the early 1970s, the European economies, too, were showing problems in restraining inflation. However, prior to 1973, the productivity-growth deceleration that marked the United States had not set in widely in Europe.

1973 clearly marks a break in trend. Since 1973, productivity growth has been slower in all of the OECD countries. Further, it has been slower sector by sector as well as in the aggregate. And, slow productivity growth has been accompanied by much more intransigent inflationary pressures and significantly higher unemployment rates than obtained earlier.

What lies behind this unhappy syndrome and why is it proving so stubborn? Economists certainly are not in full accord on diagnosis. I would urge consideration that the dominant proximate cause has been governmental policies, virtually universal throughout the OECD countries, that have been trying to restrain inflation by restraining growth of demand. These policies have been relatively successful in restraining demand growth. But, as a consequence, supply growth has been restrained as well. Until recently at least, there has been limited pressure on capacity and hence limited incentives for new investment, together with stagnation in employment. Particulary in the European countries, labor legislation has protected jobs. Productivity growth has always tended to decline when economies slid into recession. Job-protecting policies have increased this tendency.

I don't mean to say here that the root of the problem is pernicious government policies. Government policies are what they are because inflation has been so rapid, and because there is widespread political pressure on governments to do something about inflation. I do mean to say, however, that these policies, whatever their effect on restraining inflation, also have restrained productivity growth.

Let me push the analysis one stage further. Why the inflationary pressures now and not earlier? Analysts have cited a long list of factors. There are several that I think particularly germane to the present discussion.

First, I would argue that the rapid rise of living standards during the 1950s and 1960s sharply raised expectations of what might be achieved in the future, and actually intensified squabbling about how resources were to be allocated and incomes distributed. While the dispute about priorities during the Vietnam War made the allocation struggle particularly visible in the United States, throughout the OECD countries questions about whether increases in gross national product (GNP) should be allocated to public services, or to the provision of private goods, were the stuff of politics. Throughout the OECD countries there seems to have been widespread verbal agreement that the real incomes of lower-income individuals and families should be brought closer to the mean. However, when push came to shove, middle- and upper-middle-income individuals did not put up with a reduction in their relative shares. The dispute was fought out both in the arena of private wage-bargaining, and in the arena of welfare-state programs. And, by the late 1960s in the United States, and somewhat later in Western Europe, the political pressure for environmental and safety regulation, which had been building up for some time, reached sufficient force so that these demands and requirements also were placed upon the economic system.

I do not want to take even a hint of a stand here regarding which of the demands were (and are) socially most important. I only want to propose that by the late 1960s, the increasingly politicized economic systems of the West were generating demands faster than could be met even with the rapid growth in productivity being experienced then. And when, as a result partly of restrictive policies and then the great shock of the oil embargo and the oil price hikes, real output growth in the OECD countries slowed down, the problem was compounded. I do believe that to get their economies working reasonably again, the OECD countries are going to have to be more effective than they have been in balancing competing claims against available means.

But even were we to achieve this, there are two salient structural differences between the present and earlier economies that will make rapid productivity growth difficult to achieve again. I referred to both of them earlier. We have been experiencing a shift in the allocation of resources away from manufacturing and public utilities to private and public services. And through regulation we increasingly are forcing attention to non-market values in market sectors.

Rates of productivity growth in the service sectors historically have been very slow. This is partly a measurement problem, but almost certainly real rates of productivity growth in services in general have been less than in manufacturing. Thus, this shift in the allocation of resources brings down the average rates of productivity growth even if all the sectoral rates are maintained.

Regulations force attention to values that otherwise would not be recognized. Analysts differ on the costs associated with these new regulations. However, they surely increase resource costs in traditional dimensions, and shift the allocation of investment in new plant and equipment, and in research and development (R&D) toward meeting these new values and away from enhancing productivity as traditionally defined. This isn't to say anything negative about these regulations. These shifts in allocation are after all, their intent. But as we make these values count more, we well might expect slower expansion in production of goods and services as traditionally defined.

Both of these structural developments pose significant issues for science and technology policy. So does the continued economic stagnation, which I propose is acting as a deterrent to traditional industrial research and development.

Note that I am not proposing here that an earlier slowdown in technical advance was an important source of the current economic malaise. Some other analysts have proposed this. It has been remarked that R&D spending in the United States began to trail off in the late 1960s, well before the 1973–74 crunch. But the national R&D cutback is completely accounted for by declines in defense and space R&D. Most econometric studies of the sources of productivity growth have been unable to attribute much weight to spending in the areas of defense and space R&D. And private industrial R&D expenditures, which earlier econometric work has shown to be strikingly related to rates of productivity growth, held up quite well until the mid-1970s.

Since 1973, there has been significant deceleration in R&D expenditures, private as well as public. But for the most part, this is associated with deceleration in growth of real output, rather than any reduction in the ratio of real R&D expenditure to real output. There has been recent evidence, however, of a shrinking of time horizons and a growing conservatism regarding industrial research and development. This development, like the slowdown in R&D spending, is just what one would expect given the slack economic conditions.

The slowdown and growing conservatism of R&D spending, along with the shift in allocation of resources toward services and the new regulatory regimes, all pose serious problems for R&D policy. Let me now explore these.

Policy Issues Regarding Technical Change

In the preceding section I argued that the current stringency in R&D budgets, and the growing conservatism of R&D, stem from the current economic malaise. They are a consequence rather than an initiating cause. But slow and conservative technical advance can make it harder to break out of the current rut. And faster and more innovative technical advance may make it easier to get out.

More rapid technical advance can facilitate more rapid productivity growth, and hence enable wage-increase demands to be met with less inflationary pressures. I would propose that more rapid technical advance and productivity growth, far from being a threat to employment, would facilitate a reduction in unemployment. I argued above that the proximate source of today's high unemployment is restrictive government policies. If more rapid productivity growth can facilitate better control of inflationary pressures, governments will be able to relax their restraints. Thus, more rapid productivity growth may be a prerequisite for a return to higher levels of employment.

Many scholars have argued that support of long range research and exploratory development in the basic technologies that underlie a wide variety of industries, is a feasible and potentially fruitful role for government. In a few fields, such as atomic energy and aviation, the American government has pushed such policies. European governments have developed them across a broader front. Experience with these programs suggests that there is a danger of governments' getting too closely involved in making decisions as to which particular products are to be developed or which technologies are to be brought into practice, rather than concentrating on broadening the range of alternatives seriously being explored. But if these proclivities can be kept in mind and guarded against politically, then, assuming such government programs were a good idea during the 1960s, they will be an even better idea during the 1980s. The current slump and the adjustments made in industrial R&D reveal just how fragile private support of exploratory and long-range work is. It would seem an excellent idea if governments took an explicit responsibility for overseeing the adequacy and diversity of the basic technological efforts as they long have taken a responsibility for overview of basic academic scientific research.

I do not want to push the idea that aggressive government stimulation of basic technological work can be a central instrument in resolving today's macroeconomic problems. But I think it should be more widely recognized among economists that further erosion of basic technological progressivity can make today's problems worse, and that policies to stimulate greater innovativeness can be important parts of a salutary package. Over the long run, protecting basic technological effort from the ups and downs of general economic activity may be an important component of a refurbished economic stabilization policy.

My other remarks about policies relating to technical change relate to more microcosmic problems. Throughout this essay I have pointed to two major structural changes in the OECD economies—a significant increase in the fraction of resources allocated to private and public services, and a great enlargement in the scope and strength of regulatory regimes. Both of these developments pose important questions regarding policies relating to technical advance.

The evidence is clear enough that the new regulatory regimes are having a significant influence on technical advance in the sectors most affected. This was their purpose. But it also is apparent that there are significant problems involved in trying to redirect private R&D expenditures through the kinds of regulatory instruments we have been using. In the first place, uncertainty regarding future regulatory requirements may deter firms from trying to develop new products and processes significantly different from present ones, since the regulators may respond to their advent by prohibiting them. There is some evidence that this has been happening. Second, the current kinds of regulations prescribe certain dimensions of environmental insult on work hazard, but not others, and establish particular required levels of achievement with no reward for surpassing them.

Current regulatory standards tend to be set with some notions regarding the costs of meeting them and the responses they will evoke (which may or may not be justified). Sometimes the result is that the standards are met at high costs with very few social benefits; sometimes the result is that the standards are challenged and the regulators forced to back down.

At the least, cases like that of automobile-emissions control indicate that a rather strong governmentally-funded R&D program is necessary simply to enable standards to be set sensibly. Government-undertaken or funded R&D also is necessary if government agencies are to avoid being outclassed by the firms they are regulating in discussions regarding technological options, likely costs, and reasonable expectations regarding the performance of the companies in question. I would tentatively suggest that public responsibility for the funding of R&D aimed at furthering non-market values might go considerably beyond this minimal role of obtaining information. Regulations might well be set more sensibly if Congress and government agencies had to face some of the R&D costs of meeting them.

Another challenge for policy regarding technical advance is posed by the shift in the allocation of resources away from manufacturing industries to other, principally service industries, where measured productivity growth had in general been slower. While in some of the service sectors technology has changed very slowly if at all, slow productivity growth in the service sectors now exerts a bigger drag on income growth than it used to. Significantly enhancing productivity growth in such sectors as construction, urban mass transport, health maintenance, and education, is now even more important than it was before in order to achieve social gains in these areas.

Simply shifting resources into these sectors will tend to draw greater R&D attention to them. But it is highly unlikely that market forces alone will be able to affect major improvements in the technological progressivity of sectors like these. And it is doubtful that government ought to stand idly by and defer to the market for effective R&D efforts. In the first place, the organization of many of these sectors is mixed, with governments playing a large role on the demand side and often on the supply side as well. Directly or indirectly, governments have a great deal of leverage over R&D in such sectors as public housing, health, education, and urban mass transit. This leverage ought to be exerted self-consciously and intelligently. Second, in many of these sectors, like private housing, demand has been protracted, high, and growing, but not much as happened. Government action has the chance of getting something to happen.

As in the case of regulation, for the sectors where the government is heavily involved as demander or supplier, the public agencies involved should spend at least enough on R&D to know what the technological options are and what they are likely to cost. But as with the regulatory cases, I propose that here too the fruitful public role for R&D should go well beyond that minimal requirement, and should involve government finance or cost-sharing in a wide range of R&D activity. In fact, R&D spending in these fields has increased significantly in the United States over the past decade. But satisfactory arrangements have yet to be worked out.

In the case both of R&D focused on the new regulatory regimes, and R&D focused on public services, the advisability of an expanded government role is supported both by its natural access to relevant information and by the legitimacy associated with an acknowledged public responsibility. It will be harder for governments to establish an effective, active R&D policy where there is no strong recognized public responsibility for the values or the services in question, particularly if private suppliers view each other as competitors. Perhaps the most successful example of public funding and subsidization of private-sector activity is to be found in agriculture. Another is public support of the basic sciences and of much of medical technology. In both of these cases public involvement could be justified politically by appeal to the role of the state in assuring that basic needs are met. But roughly the same kind of argument also could be, and was, put forth in the various efforts in the 1950s and 1960s to mount public programs in support of housing technology. The proposed policy departures never were actively implemented. The latter case is differentiated from the former ones, it seems to me, by the fact that suppliers of inputs into housing construction considered each other as rivals. Public support of R&D relating to housing therefore was viewed as posing a sharp threat that some firms and industries would be helped and others hurt. This perception undermined the legitimacy of government programs and was sufficiently effective to keep them bottled up in legislature.

As I understand it, the current struggle with respect to the government's role in energy-related R&D reveals a similiar syndrome. While a broad public responsibility is not questioned, the issue of where public responsibility begins and private responsibility ends involves not only questions of who is in a better position to make decisions and where private incentives are strong and weak, but also the constraint that public funds should not significantly upset the balance of private competition. But, the requirement that public research and development support not upset the private balance can come close to a constraint on public R&D not to generate anything significantly different from what private R&D would have come up with in the first place.

I flag this problem because I think it is a serious one. My arguments herein call for a significantly greater role for public decision-making and public funding of applied R&D. While such a role will inevitably benefit most of us, it will erode the interests of some of us. All of us concerned with identifying the important science and technology issue of the 1980s should be very aware that it is one thing to identify and argue rationally for a new set of policies, but it is something else again to get these policies accepted politically without emasculation.

THE REVIVAL OF ENTERPRISE

By Theodore J. Gordon*

CONTENTS

As I considered the prospects for the revival of enterprise—particularly enterprise in the United States—I sought to answer five questions:

Was enterprise ever as real and as intense as we remember or is it vital only in recollection—a trick of memory?

If it was real, have things changed—has enterprise diminished?

If it has diminished, why?

Given the reasons for the shift, can it be revitalized?

Even if it could be , should it be? Do we really need enterprise in the years ahead or has its time, like Victorian morality, passed?

When I began the exploration of these issues I was not at all certain about the outcome—in the end there are no black and white answers, only hints. But the hints are strong and suggest enterprise needs to be revived—and probably can be—in the interest of us all.

Let me first define enterprise. It is different, I think, from either productivity or innovation. Productivity in the economist's sense is output per man-hour. Enterprise, in the way I use it here, involves bold, hard, and important undertakings. Thus, not all productivity is enterprising, nor all enterprise productive. For example, consider that someone comes up with an effective plan for cutting health care costs. This would certainly be enterprising but might not result in an increase in economic measures of productivity. Similarly, more efficient production of trivia might increase economic measures of productivity but is not enterprise.

At this conference we have heard a lot about the difference between quantity and quality. To a degree that's the kind of distinction involved here. Innovation deals with the process of invention and market introduction of products and services, and its measures are independent of what is innovated; productivity is a very limited measure of the efficiency of the economy—output over input; it doesn't deal with what is produced. Enterprise, however, is concerned with ends and their achievement and therefore inevitably deals with what is innovated and produced, and the spirit which engenders invention and production. It is purposeful production.

*President, the Futures Group, Glastonbury, Conn.

Enterprise involves values and is, therefore, a much more difficult notion than productivity which is reducible to an arithmetic construct. What is bold and hard and important (that is, what is enterprise) depends on values (that is, what is perceived as being bold and hard and—particularly—important). Since values change with time, what is considered enterprise changes with time as well.

In a nutshell I reached these conclusions about the five questions I posed. Yes, enterprise did once flourish in our country and has now diminished in intensity. The reasons for its current lack of vigor are hard to pin down exactly but include satiation, diversion of resources from so-called "productive" to "unproductive" pursuits, unbalancing of rewards and risks, and above all, increased uncertainty occasioned by inflation and regulation. Uncertainty results in a short-term perspective. There are many proposals for encouraging innovation and productivity but their effectiveness is not known. Even if these proposals work as intended and they stimulate innovation and productivity, they may not rekindle enterprise. Yet the opportunities and, more importantly, the needs for enterprise, abound, and in some instances at least, the revival of enterprise seems the only means of avoiding suffering of great magnitude and intensity and improving our mutual lot.

Let me review briefly these five questions and some of the ideas which occurred to me as I pursued them.

1. Was Enterprise Ever Real in America?

Of course it was. Over the last two hundred years in our country there was a spectacular confluence of forces that gave rise to unparalleled economic and social growth. Markets were created by the growing numbers of people in our country, their inexorable move toward the West, the entry of the United States into world trade, and the spectacular rise in affluence by any measure—quantitative or qualitative—of the average American. These markets could be served because of a vital labor force—sometimes imported, the ready availability of inexpensive raw materials, and the creation of a national capital base. And these forces came together in an era of invention that ran continuously from the first beginnings of electromagnetic theory to large-scale integrated circuitry; from the frontiers of western Massachusetts to the frontiers of space. And the invention was not confined to mechanical devices; it pervaded the social arena as well. We saw in this same interval the transition from an agricultural society to an urban culture; unprecedented experiments in freedom of lifestyle from generation to generation; the growth and demise of imperialism; the advent of bipolar military stability; development of the corporate form and the regulatory structure that shaped it; the shift from exploitation of the environment to its preservation and restoration; changes in authority and structure of almost every institution from the family to the church and school; even changes in what constitutes the "good life."

The weave of this fabric of enterprise and growth is extremely complex and it is very difficult to separate cause from effect. Without innovative technology, the labor, capital, and raw materials would have been devoted to mundane improvements, not the fireworks of technological revolution. Without social innovation, all would have been a rigid exercise in the preservation of archaic and static values. But the whole was dynamic, vital, discontinuous, explosive; and the consequences are undeniable.

Certainly in all of this there were excesses and abuses. The line between enterprise and exploitation was often blurred and vague and changed as modern values emerged. The common environment was used without question as a source and a sink for production. Child labor was not only acceptable at one time but considered a virtue. Trusts, clearly seen as exploitive in retrospect, were the economic engine for accumulating capital which, reinvested, promoted growth and social development. In short, the virtue of enterprise and the evil of exploitation could not, cannot, be defined in any absolute sense established by measurable specifications which are unchanging with time. Rather, they are concepts evaluated in terms of the morality of the moment.

Our call for quality as opposed to quantity would have been unintelligible to people striving for survival or seeking security (and still is).

In short, enterprise was real in America and its fruits are abundantly evident. But what was meant by enterprise has changed over time as values have changed. Earlier enterprise evoked Horatio Alger individual achievement, national triumphs and accomplishments in growth, accumulation of wealth, being the best, zero sum—I win, you lose. Innovations and productivity were its instruments. Now the search for modern enterprise leads us into uncharted territories.

2. Have Things Changed? Has the Level of Enterprise Diminished?

While productivity and enterprise differ—one value laden and the other not—in a society suffering from lack of enterprise, dropping of productivity is probably symptomatic of the basic malaise. Since productivity can be measured directly and enterprise cannot, let me for a moment focus on productivity and then extend the conclusions to enterprise.

That productivity growth in the United States is down, is well known. It can be seen directly in economists' measures of output; in government spending for research and development (potentially a cause); in our competitive position with other nations in the absolute number of patents issued; in the relative number of patents issued by the United States Patent Office to U.S. citizens and to foreign applicants; in the growth of government, particularly state and local government; in the difficulty small business faces in attracting capital (small business is typically more innovative than larger business); and in the declining percentage of new product introductions originating in the United States.

There are no indicators to the contrary: things have changed, productivity growth has diminished. In terms of innovation, productivity, competitive position, or even a qualitative feeling of vitality, the trend is apparent everywhere.

While measures of productivity are relatively simple for manufacturing industries, measures in the service sector are much more difficult. How does one measure, for example, productivity in government? Can the productivity of a police force be measured in terms of its traffic citations per officer? Economists have been able to develop an implicit measure of productivity of the service sector but they are shaky.

In the time that we recognize in retrospect as enterprising, would these same statistics have shown the vigor of enterprise? Certainly to some degree. But missing from the numbers would be the spirit of the time, telling those who dare that innovation is not only acceptable but desirable; that creativity is not a disease; that aspiration is not an aberration but the norm; that achievement, even individual achievement, is possible and to be revered; that institutions can work, and work in the interest of those who are served. These sentiments, to varying degrees, are seen as obsolete today, and that is the strongest indication that enterprise has diminished.

3. Why Has Productivity Diminished?

Given that productivity has diminished in its vigor, what are the reasons? I came across fifteen reasons in the literature—there are probably more.

Productivity growth is down because of rapid energy price escalation.—Recent energy price increases have lowered productivity by decreasing the rate of growth of capital stock (through diverting of capital that might have been used to increase productivity), by making energy-intensive processes unprofitable and some capital stock obsolete, and by making labor substitutes for energy more feasible than was previously the case. (But note that price escalation also acts as an enormous stimulant to innovation.)

Productivity growth is down because of inflation.—The effect of inflation on productivity is complex. Clearly, diminishing productivity growth adds to inflation; less obviously, inflation contributes to diminishing productivity growth. In the presence of inflation, uncertainty is higher and long-term commitments to industrial research are diminished. Inflation acts to deter venture capital, equity investment in entrepreneurial activities, and even long range corporate projects, since the return-on-investment equation always requires some future estimate of income. Venturesome projects reach "break even" some years hence; the changing value of the dollar in the interim can make otherwise attractive projects quite uncertain. Inflation alters the rate of return for new investment that businesses can accept. In the presence of inflation, businesses seek faster recovery of capital costs, and that shortens the planning horizon.

Productivity growth has diminished because after-tax profits have declined.—The facts are clear enough: after-tax profits of corporations in the United States averaged about 8 percent of sales during the mid-1960's and currently average around 4 percent. The lowering of after-tax profit impedes the cash flow of American industry, and restricts capital availability for new ventures by investors. Double taxation of corporate dividends and long periods of capital recovery for investment in plant and equipment tend to amplify this factor.

Productivity growth has diminished because of the changing work force composition.—Over the last three decades the labor force has grown more than 50 percent primarily as the result of the entry of young people and women into the labor force. The influx of less skilled, less experienced persons, combined with earlier retirement of skilled adult men, is presumed by some to have reduced overall labor productivity. Furthermore, while the educational attainment of the labor force has been increasing, it has been slowing in its rate of increase. As rate of educational attainment slows, productivity increases from this source slow as well.

Productivity growth has diminished because of the dynamics of the shift of labor from agriculture to industry.—Since productivity in agriculture is generally below productivity of other economic sectors, the shift from agriculture to other sectors generally represented a trend in the direction of increasing productivity. Now, with that shift completed, this source of productivity growth has ended.

Productivity growth has diminished because technological progress in the mid-1960's was exceptional.—The spin-offs from the space program were coming to market in the sixties; integrated circuitry was finding product applications; American technology was a stimultant to international trade. Now that push is behind us.

Productivity growth has diminished because of increasing emphasis on antitrust actions.—Conflicts often exist between antitrust objectives and other social goals. For instance, the patent laws reward creativity and technological innovation in contrast to the competitive demands of antitrust. One requires disclosure, the other secrecy. Large corporate mergers present classic questions of efficiency versus competition. In general, antitrust actions—or the threat of them—tend to increase uncertainty and promote a short-term focus.

Productivity growth has diminished because of excessive expenditures on weapons.—U.S. expenditures are high, averaging 5.4 percent (constant 1975 dollars) of the GNP in 1976. Furthermore, CPFF [cost-plus-fixed-fee] contracts penalize improved efficiency.

Productivity growth has diminished because of new product liability concepts.—The liability associated with products now extends over long periods of time and "ripples" back from the manufacturer of the product to lower echelon suppliers. The threat of continuing liability of uncertain size, evoked by conditions of use not under the control of the innovator, probably leads to less innovation.

Productivity growth has diminished because of worker dissatisfaction.—According to this interpretation, diminishing productivity growth stems from worker dissatisfaction and alienation; worker frustration stems from bureaucratization and segmentation of the work process and overqualification for jobs.

The other side of this coin involves the activities by organized labor that are designed to preserve jobs irrespective of the possibility of technological improvement. This is known as "job security" and is directed against the possibility that technological improvements, such as automation, could eliminate jobs or that jobs would be eliminated as a result of moving production facilities to another geographic location, particularly offshore. Over the past several years job security has emerged as a major bargaining issue. Previously it tended to be cyclical, with increase in job security clauses after economic recession. The current emphasis is based on more than cyclical trends and, therefore, cannot be expected to abate quickly.

Productivity growth has diminished because of egalitarian drives that make entrepreneurship less rewarding.—The egalitarian bent of our society, the argument goes, requires that gains be distributed—but entrepreneurship by its nature is pursued to achieve unequal gains. When such gains are perceived as "greed," inhibition is inevitable.

Productivity growth has diminished because limits to growth are being approached.—In this view, in the past, society used easily available resources. These were cheaply obtained and processed. Now, it costs more in terms of capital and human effort to obtain a unit of output.

Productivity growth has diminished because of inappropriate Government intervention in the free market.—In this view diminishing growth in productivity stems from tampering with the free market system. The domain of tampering is extensive and includes excessive individual taxation that lowers work incentives, and regulations that require unwarranted corporate expenditures. Wage/price guidelines result in misallocation, shortages, and uncertainties that reduce efficiency.

Productivity growth has diminished because of the adverse regulatory climate.—Regulation causes diversion of resources from other more productive channels. But recognize that so invested, something is bought other than productivity. There is no way to account for cleaner air and water and improved worker health and safety in the current economics of productivity. Thus the loss in productivity growth may be a myth, an artifact of the way we account. If we could include the improvements in the environment in the productivity equation, perhaps growth would still be increasing.

Productivity growth has diminished because of satiation. We've got what we want, most of us. Entitlements guarantee it whether we work hard or not—why push? That's the batch—everybody sees in the situation a reflection of their own prior biases, from Marxist to Keynesian. Perhaps they're all correct, to some degree.

4. Can Productivity Be Revitalized?

Productivity is in this year. The Domestic Policy Review (DPR) of DOC [Department of Commerce] and the Council of Economic Advisers (CEA) are conducting studies into productivity; congressional committees are holding hearings on the topic. The reasoning behind these activities is that productivity growth in the country is waning, lagging behind Japan and West Germany. This puts us at a disadvantage in world markets, hurts balance of trade, and is inflationary. Public policies can induce increased innovation, and innovation will stimulate productivity. Improved production will lower prices and make our products more competitive on the world market. Thus it is anti-inflationary and job creating. The recommendations of these groups are far reaching and include (as examples):

Changes in corporate tax policy to encourage investment and R&D.

Promoting commercialization of inventions made under government contracts or in government laboratories.

Improving the support of research and development associated with generic technology, that is, technology that can spawn a large number of downstream products and processes.

Improving incentives for small business. These incentives might include stock option time limitations for founders and key personnel, postponing tax on income derived from sale of shares by founders, allowing start-up losses to flow free to founding investors, allowing tax-free rollover of equity investment in small businesses, etc.

Promoting international trade, particularly export activities of American firms.

Organizing information relevant to the innovation process, and making it available in a timely manner to potential entrepreneurs.

Reducing inconsistency of regulation or uncertainty of regulation standards.

Focusing regulations on standards of performance, not the processes used to achieve the standards.

Studying the consequences of regulations before implementation. Many new regulations have many unintended consequences; for example, new regulations have caused many smaller firms to close and larger firms, as a result, have increased their concentration in various markets. This was often accomplished through acquisition, a consequence certainly not intended by the original regulation.

Amending antitrust policies to reduce their effect on innovation.

Where product safety is involved, employing product performance standards rather than detailed design standards.

Limiting product liability to a specific number of years after a product is introduced in the marketplace.

Amending patent timing. Where regulatory approval is required of a new product before its introduction to the market, patent issuance should coincide with the approval date.

Is all of this whistling in the dark? Can the government fix it? The public is mistrustful of both big government and big business. Many people are reluctant to accept the word of government as absolute truth or many of its actions as necessary; as for business, many people feel that corporations generally act in their own interest (even when such action endangers the health and safety of their workers and customers) and distort the truth as well. In short, there is a loss of confidence in both government and business and their ability to act for the public. This expressed lack of confidence is a mark of our time.

Yet, the public looks to government to provide their growing list of "entitlements": jobs, housing, health care, education, financial security, and clean air and water. The growth in the demand for job security is a manifestation of this "entitlement" attitude. In many instances, business is the instrument by which government accomplishes these ends; if business can't, or is profiting unduly, the prevailing attitude is that the government should perform the function. Because of mistrust, changing values, and pressing societal issues of unprecedented complexity, urgency, and importance, a new contract is being forged ad hoc, piece by piece, between government, business, and society.

Even if these policies work, they may not be sufficient; they do not assure a return to enterprise—a willingness to venture on bold, hard, and important undertakings with energy and initiative. Perhaps we as individuals, and the institutions we have created, are beyond that point. Why, after all, should we do hard things when "entitlements" let us survive? In the end, to revitalize enterprise requires attitudinal shifts reminiscent of President Kennedy's instructions: We must, and our institutions must, ask what needs to be done, not what's coming to us. This requires a means for searching out goals and making our measures of achievement coincident with goal attainment, not raw production. This goal reward should work at all levels.

For the nation this means creating incentives for institutions and individuals which reward contribution to unambiguous national goals. For business this means profit-sharing with employees and customers. For labor this means tying compensation to productivity. For society this means relating "entitlements" to needs.

5. Should We Seek To Revitalize Enterprise?

Granted that innovation and productivity, or even enterprise, could be stimulated. To what end? I believe the problems which we have now or which appear on the immediate horizon require revival of enterprise; without it, these problems will be more severe and lasting. The problems requiring hard, bold, important action include:

Those which flow from the increasing numbers of people who, without accelerated innovation and productivity, would be doomed to crushing poverty.

The "problematique," that confluence of global issues, largely stemming from population and economic growth, including adequacy of food, energy, resources, and the environment.

The control of nuclear proliferation, repairing the frailties of the world monetary system, dealing with terrorism, urban renewal, immigration, conservation without stagnation, improving agriculture production and the balancing of inflation and employment within the United States and other countries. These issues cry for sensitive, intelligent, inspired enterprise; with it these issues may be overcome; without it, the risks are great indeed.

These examples illustrate the need for enterprise; coincidentally, there is a plethora of nascent technologies which, through planning, can be utilized to advantage. These include the following:

The microelectronic revolution, which will manifest itself in robots, computers, electronic books, electronic photography, flat wall television screens, listening and speaking machines, artificial intelligence, appliances that reason, games that are fun and human-like creative machines, and new processes and their control. This technology is relatively inexpensive and will help provide education, communications, and organizational efficiency.

Genetic technology which offers the possibility of designing plants and animals with desired properties. Before too long this technology will find application in agriculture, animal husbandry, medicine, mining, environmental control, water purification, aging research, botany, and control of chemical processes by providing a new means of catalysis.

Nutrition is a kind of a black art today, but improved epidemiological analysis may help identify the health consequences of various diets and environments. We are on the frontier of making nutrition a science by finding out how various things we eat and do influence health, disease and vigor.

Biomedicine is likely to undergo significant improvements in the years immediately ahead. Life expectancy at middle age will begin a dramatic climb. Vigor in middle age and early old age will improve. This will have important consequences for retirement and the nature of work.

The psychology revolution, which will add to our understanding of how the mind functions, how thought is stored and recalled.

Agricultural technologies, including those which will add to growing areas of the world, increase productivity, provide new sources of protein, or improve the quantity of nutritious food which is finally delivered.

Communications and information technologies that make practical the storage and retrieval of large amounts of data almost instantly at trivial cost, present essentially any program to small audiences with great flexibility, and increase the potential for direct education.

This list is obviously incomplete and in retrospect we will find other technologies which have had even greater impact on the world scene two decades hence. Yet, even with these omissions, the technological opportunities on which enterprise can build seem profound indeed.

How then might enterprise, sensitive and intelligent, be revived? Certainly the proposals directed toward stimulating innovation and productivity will help, but beyond these, hard, bold and important action requires fundamental changes. Here are some ideas:

We have lost the belief, or the courage to enforce the belief, that good performance should bring rewards and bad performance should not be rewarded. Corporate incentives should be linked to the achievement of societal goals. We do this ad hoc now: there was, for example, a jobs tax rebate to help lower unemployment.

Wages should be linked to productivity and profits. With wages linked to productivity and profits, enterprise is carried to the level of the individual. Inflationary pressures subside, competitive stance improves. With these first two ideas in place, the invisible hand writes not to suboptimize individual or corporate gain, but to accomplish higher ends.

We have fooled ourselves with inadequate measures of productivity. Clearly, new measurement systems are in order that are quality oriented—that recognize our movement toward services—that measure problem severity or goal proximity.

We should track the consequences of our poliices. It is not enough to debate policies before the fact; it is essential to track and evaluate the results after implementation.

But what goals are appropriate? How can diverse interests be balanced? How can public views be generated and more effectively injected into the decision process? National goal efforts, after all, have been notoriously unsuccessful. Where is it that we want to go? Knowing this, most else can follow. Harland Cleveland said, "Planning cannot be detailed regulation by Federal agencies—planning will be improvisation by each of us on an agreed sense of direction." The revival of enterprise needs that sense of direction. We need planning that identifies issues and ties rewards to their solution.

Some national programs have galvanized action; the most inspired of these have organized national purpose, captured imaginations, and harnessed enterprise; for example, the Apollo program. Other national programs have been no more than weak slogans, seen as ineffective by both cynics and supporters; for example, The Great Society. The differences between these involve clarity of purpose, perceptions about need and self-interest in the program, and the charisma of the program's champion. The United States needs new effective programs in energy, agriculture, ocean utilization, and urban redevelopment. Properly framed, these can stimulate enterprise in the interests of society.

Enterprise is like a giant engine, idling now, but capable of great energy. We should point it at our problems and turn it on again, if we can.

THE ROLE OF IMBEDDED TECHNOLOGY IN THE INDUSTRIAL INNOVATION PROCESS

By Albert H. Rubenstein*

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FIGURES

*Professor of industrial engineering and management sciences and principal investigator of the program of research on the management of research and development, the Technological Institute, Northwestern University, Evanston, Ill. He is also president of International Applied Science and Technology Associates (IASTA, Inc.), a consulting firm in the R. & D./Innovation field, and a member of the board of directors of Narragansett Capital Corp., a small business investment company.

1. What Is Imbedded Technology and How Does It Relate to the Overall R. & D./Innovation (R. & D./I) Process in the Private Sector?

1.1 Introduction and Some Definitions [1]

In most discussions of technology transfer, the innovation process, productivity, and other tecnhology-related subjects, there is generally an area of uncertainty and concern which revolves around the issue of "the secret of success" or the "reasons for failure." Comparisons among countries, industries, sectors, and individual firms involve attempts to identify and explain these "secret ingredients" of technological superiority or lag. Certainly, differences in level of Research and Development (R. & D.) or Science and Technology (S. & T.), roughly equivalent terms, are used to account for some of the differences among the most advanced countries (industries, firms, sectors) and those least advanced.

The problem is that the usual indicators of R. & D. or S. & T. depend heavily on numbers such as expenditures on R. & D., numbers of engineers and scientists, and the size of laboratories. Such numbers do not explain enough of the differences in technological capabilities and performance to provide guidance for policymakers.

There are also contradictions. Some countries, industries, sectors, individual firms, and major parts of firms (e.g., operating divisions) appear to be spending a reasonable sum on R&D and appear to be employing adequate numbers of scientists and engineers (in some cases excessive numbers, according to critics.) Despite this, however, entities with smaller R. & D. budgets and smaller numbers of people appear to be more capable of "getting products out the door," achieving technological innovation, producing high quality and reliable products and services, and performing other technologically related activities in a superior manner.

Many of the discussions mentioned above, at conferences, in classrooms, in board meetings, in the press, and in common parlance, refer to other factors and not to R&D or S&T. Among these other factors is one which has been kicking around under various labels since well before the days when "Yankee ingenuity" was recognized as a force in world trade and the development of this country. Although there are many terms used for this phenomenon I have chosen the term

[1] This paper was not intended as a literature review and hence no thorough search of the literature on this subject was conducted. Included in sec. 7, however, are references selected from the hundreds of articles and reports related to the general area of imbedded technology. References in the text typically refer not to this external literature but to our own POMRAD and IASTA research and consulting reports related to IT, to provide the interested reader with the opportunity to follow up for more detail and background on some of the points made.

"imbedded technology" (IT) as a convenient hook on which to hang the ideas in this paper. I make no attempt at an elegant or rigorous definition here and am not sure that one is feasible or that one would satisfy all interested parties. Imbedded Technology, as I am using the term, involves several concepts, very loosely defined:

(*a*) Specific knowledge which is: (1) embodied in materials, products, processes, procedures, and systems; and (2) accrued or appeared in a gradual, non-breakthrough manner.

(*b*) Ideas for or knowledge of how to make improvements in materials, products, processes, procedures and systems which may not have been specifically incorporated, but which may be available "on the shelf."

(*c*) The variety of individual technical skills which are not readily classified or even described, but which involve accumulated experience on how to do things, and what works and what doesn't work.

(*d*) The aggregate clusters of individual skills which make up organizational capability—a first rate design group, a savvy start-up crew, a clever and innovative methods department.

Many other terms have also been used to describe the range of phenomena included in this broad definition (Hahn, and Doscher, 1977):

Technological infrastructure.
Systemic technology.
Technological diffusion.
Microtechnology transfers.
Evolving technology.

In some sense, imbedded technology (IT) is a residual when the formal R. & D. components of the overall R. & D./Innovation process are removed. One test for "stand alone" IT is the appearance of innovation and technological capability in the absence formal R. & D. or S&T institutions and roles. Examples of manufacturing-related IT's are given below, in section 3.2.

The main purposes of this paper are to contribute some insight into the phenomenon of IT, to describe its role in the overall R. & D./Innovation process, to suggest some means of better identifying and measuring it, and to discuss some public policy implications of IT.

1.2 A Flow Model of the R. & D./Innovation Process and the Role of IT in R.&D./Innovation

In a previous paper for the Joint Economic Committee (Rubenstein, 76/1),[2] I presented an abbreviated flow model of the R. & D./Innovation process which we have been using for several years as a framework for our attempts to identify and develop indicators for outputs of the various stages of the R. & D./Innovation process (Rubenstein and Geisler, 78/54). To date, we have used this in several studies in the United States and Brazil in a number of sectors, including: the environment, industry, small business, health care, transportation, energy, materials and agriculture. Figure 1 is an expanded version of the original flow diagram of the earlier paper.

In addition to attempting to identify and formulate indicators for the outputs of each stage of the flow process (boxes 2, 3, 4, and 5 in

[2] Document numbers of POMRAD, see sec. 7.

fig. 1), we have also been concentrating on the various barriers and facilitators at each stage of the R. & D./Innovation process (boxes A, B, C, and D) and have, in this diagram, collected them into the long box at the bottom of the figure. In several of the studies, we have developed specific lists of barriers and facilitators for each stage and for each specific sector or field of technology being investigated. This work on "R. & D./Innovation Indicators" is still in an early stage and much remains to be done before useful and credible integrated indicators are available for specific fields and technologies.

Imbedded Technology (IT), according to the definitions in section 1.1, plays an important role in the transitions between each pair of adjacent stages and in the overall R. & D./Innovation process. For example. box B is, to some extent, an "IT stage" of the R. & D./I process. It involves many of the design, engineering, and production innovations which are added on to or used to replace the original product or process features and specifications that emerge from the "upstream" or R&D stages of the overall process. Many specifications and features turn out to be non-feasible, non-economic, unsafe, too time-consuming, difficult to maintain, difficult to operate, and unmarketable. At this point I do not wish to join the attack, which comes from some quarters, on the impracticability of much work done by scientists and engineers in or for industry. My theme is that science and formal engineering alone are far from sufficient to turn out useful products, services, and processes. For this reason (and in many cases, out of time sequence), the IT intrastructure has been developed and is maintained. Examples of the kinds of skills and activities covered by IT include tool and die making, computer programming, and methods and standards. Additional examples are given in section 3, below. In this section, I am concerned with the ubiquitous role of IT and all it implies at every stage of the R. & D./Innovation process, from the making of a drawing or model to the tricks of the trade in adapting a product or process to the specific needs and barriers of the social subsystem (box 5 in fig. 1) or market for which it is intended.

1.3 Relation of IT to Institution Building, Capability Development, and Productive Infrastructure

Three examples from three quite different situations are given to illustrate the impact of IT on a wide range of technological situations: New high-technology small companies in the U.S., research institutes in developing countries (LDC's) and large multi-national companies (MNC's). All these situational examples are composites from research and consulting experience on all phases of the R. & D./Innovation process over the past 25 years. All three reflect the attention to the IT components of institution building and capability development for R. & D./I, often overlooked by policymakers, financiers, and non-technical management people.

(*a*) New, high-technology firms grew like mushrooms and like topsy on both coasts of the U.S. and at several isolated inland locations in the U.S. after WW II. Most of them, in the early post-war days, arose from university or government laboratories and represented applications or continuation of the science and technology

(S&T) that their founders had been conducting under the umbrella of the lab or university. As long as companies continued their "studies and prototype development, contract R. & D., and made "one of a kind" highly specialized and complex instruments and equipment, they performed well (although few made profits early on, let alone, paid dividends).

When, however, they branched out into commercial products or processes and attempted to go into quantity production under cost and time constraints, many of them came to a grinding halt or went through formidable gyrations and changes in organization, personnel, financing, and ownership.

Much of what was lacking was a sufficient level and quality of IT. In the simplest view, most of these technical entrepreneurs and their friends who also came from non-commercial environments, were lacking in most skills required to put out a competitive, practical product. The most serious shortcoming for many of them was complete lack of training in, experience with, or understanding of the production process and many special functions that are involved in producing a technology-based product or process. In the late 1970s, with many of the lessons about production technology learned by their entrepreneurial "ancestors," many of today's founders of such firms still do not have the requisite skills and knowledge to manufacture properly and many of them still do not recognize this gap.

I have been personally affected by this situation for the past two decades as a director of a Small Business Investment Company and, for many years, a prime advocate on the Board of high-technology "start-ups." Although there are notable exceptions, the typical high technology start-up company which spins off from a university or government lab is almost completely lacking in the range of individual skills and company capabilities (IT), unless they are fortunate or foresighted enough to have included some partners or employees with previous industrial manufacturing and engineering experience. One of the consequences of this gap in company capabilities is the offsetting in the marketplace, both domestic and international, of the highly innovative nature of their products (the raison d'etre of such companies) by high costs, long delays in production, and product features which often fail in service or in the marketplace due to lack of certain ITs. In addition to lack of basic IT capability, many of these new high technology firms suffer from the common weaknesses of many new and small businesses—inadequate marketing, financing, and general management skills (Rubenstein, 58/1).

Several programs of the National Science Foundation (NSF, 1978) and other agencies have recently been directed toward this category of small high technology firms and it is possible that remedies for some of their IT deficiencies are forthcoming. One danger is that the typical partner arranged by matchmaker Federal agencies is a university group which often lacks the same IT capabilities as the firm seeking help.

(*b*) Research institutes (RI's) in developing countries (LDC's) play a unique role. Many of them are the only relatively sophisticated source of technology for industry or other sectors. They can (although not always successfully) serve their clients as "windows to the technological world," providers of technical assistance, and sources of scientific and technical information. The common problem, however, is that many of these RIs (the majority in some views) are no better off in terms of the range of capabilities needed for industrial innovation and production than the new high technology firms discussed above. Their personnel typically come (with a few notable exceptions) directly from university or government science departments, laboratories, or bureaus. The exceptions are those few whose top management and senior personnel are deliberately recruited from industry to head the RI or which, in entrepreneurial fashion, are established by experienced industrial people.

Our work with dozens of such RIs in Asia, Africa, Latin America and elsewhere (Jedlicka, et al., 75/7) suggests that most of them do not have the depth of experience or understanding of the range of ITs needed for effective product and process development along the entire R. & D./Innovation chain. Therefore, the advice they provide their clients is often amateurish with respect to modern techniques in engineering, tooling, procurement, marketing, and production methods and, eventually, if not sooner, industry turns away from them and seeks help elsewhere or does without.

There are many reasons for this mismatch between RI and client needs, in addition to the university bias of its personnel, and they have been discussed in countless conferences and surveys. It is not clear that international organizations which originally set up most of the research institutes (RIs) or that national agencies (ministries, departments, bureaus) which are responsible for operating them recognize even today the important role that IT capabilities play in the RI-industry relationship. It is also unclear whether they are doing much to remedy the situation.

One approach we have been pursuing to contribute to improving the situation is to recommend broadening and deepening the scope of activities of such RIs to go beyond the typical "doing of projects" and "providing of technical information" into a fuller partnership between RI and client along the entire R. & D./Innovation process rather than merely at the "front end" or R. & D. part of the spectrum (Rubenstein, 75/109, 76/50).

The role of the RI has tremendous potential impact on helping to build the productive infrastructure of individual companies, industries, and the economy of an LDC as a whole. This is particularly important in LDCs, since the typical company is very small or tiny by U.S., European, or Japanese standards and often does not have a single college graduate or person with deep and broad experience to do the range of activities included under IT, let alone have formal multi-person R. & D., or engineering departments.

The RI, in theory, can assist in providing the IT help needed by many such firms and help them build in-house capabilities for the range of ITs needed. This can be done with the cooperation of the emerging industry association and other technical assistance bureaus in some LDCs. Unless most of the RIs remedy their own lack of IT capabilities, however, they can be of little use to their clients.

(c) Large multinational companies (MNCs) provide the model for the full range of IT capabilities needed for modern innovation and production. Even here, however, some problems appear. When the outer skin of a huge diversified MNC is peeled away, we often find a collection of relatively small companies or operations which, according to "decentralization" doctrine, are expected to operate in a fairly autonomous manner except for financing and some general corporate-wide policies. In many of the top 100 U.S. corporations, mergers and acquisitions of autonomous companies created the operating units. The apparent synergism between units that should provide for skill and capability exchange at the level of innovation and production is not very effective. That is, within the large corporate framework, many smaller divisions are lacking at an acceptable level some of the basic IT capabilities and others have a surplus. We [3] have been acutely conscious of this in our small business investment (SBIC) activities in recent years, as we have concentrated on "buy outs" of divisions and operations of large diversified companies (several dozen over the past decade), finding many of these units, when stripped of corporate staff support, sadly lacking in basic elements of IT when they are set up as independent small businesses with their former managers becoming the new owner/managers. This situation is a far cry from the new high-technology companies discussed in (*a*), where most of the personnel are relatively inexperienced in industry. In the case of the "buy out" that leads to a new "stand alone" company, the management and other personnel are quite experienced (we would not back them in a new venture if they were not) but frequently they can no longer afford the luxury of specialized IT capabilities which they formerly obtained "free" (as part of the overhead they paid to corporate staff) or paid for on a pro-rated basis.

Few of these small new companies can afford the highly specialized people in quality control, operations research/management science, market research, law, corporate finance, logistics and transportation, data processing and other special capabilities they enjoyed when the organizations were part of a large corporation. In instances where the parent corporation displayed the extremes of decentralization and autonomy—allowing the division manager the option of "buying" such specialist services—many of them declined and did without or used fewer highly specialized people to perform the needed functions.

A relatively new problem in relation to IT in MNCs has emerged recently, although symptoms have been observed for many years. This is the steady loss, through retirement and lack of renewal, of many of the skills that make up the range of IT capabilities in a manufacturing firm. This was brought home to me abruptly a few months ago, when one of my clients—a top 100 company—offered early retirement (55 years old and up) with a benefits package that many people felt they could not refuse. The resulting exodus of highly specialized manufacturing and engineering people (both inside and outside formal R. & D.) was a profound shock and has left a

[3] Members of the Board of Directors and Management of Narragansett Capital Corporation, currently the largest of the publicly held Small Business Investment Companies (SBIC's) of which the author is a director. Narragansett's investment strategy is described in "How I'm Deconglomerating the Conglomerates" by Royal Little, founder and former chairman of Narragansett in "Fortune," July 16, 1979.

number of critical holes in the range of ITs in several operating divisions and corporate staffs. A rationale might be that it gives younger people the opportunity to advance, and this is true; but it is also true that for many of these early retirees (as well as "on schedule" retirees), the company had not trained or recruited sufficient talent to back them up and replace them.

These three disparate examples illustrate the widespread nature of the IT phenomenon and the different circumstances under which lack of adequate IT capabilities can occur or persist. All three relate to the constant institution- and capability-building required to develop and maintain a productive infrastructure to back up the R. & D./Innovation efforts of a company, an industry, a sector, or a country.

2. Why is Imbedded Technology Important to the U.S. Economy?

2.1 IT is a Necessary Condition for Successful Technological Innovation

"Imbedded", "non-obvious", "infrastructure", "know-how" technology is a dominant factor in the U.S. past and current position of technological and commercial leadership in many fields. It represents skills, knowledge, people, and organizational capabilities which support industrial innovation.

This is not to say that formal Research and Development (R. & D.) has not been and will not continue to be a major factor in this success and that published and patented technology are not critical to our leadership position. IT does, however, constitute a necessary condition for this leadership position and without it the economy would be unable to fulfill the potential provided by R&D results, including patents.

As indicated in the first section, the complete innovation process involves the application of the capabilities included in IT at all stages of R&D/I. The arts involved in actually designing and producing a product predicted by theory or getting a new, patented process to work efficiently and economically are generally not transmitted through textbook instruction or formal algorithms and paradigms. These are learned behaviors which can be transmitted by various means but which require time, personal interaction, and much trial and error.

And herein lies the essence of IT's role in the innovation process. For example in the coming shake-out in the computer peripheral and softwear field, dozens and even hundreds of "marginal" operators will fail, due in part to lack of essential IT skills, if the growth patterns of many other markets for new technologies apply in this case.

For another example, we have recently done a "fish or cut bait" study for one of the hundreds of firms which have plunged into the water treatment market with new devices, systems, materials, and services. Few have made any money and the vast majority will fail or abandon that line of business over the next few years. The failures will not all or even largely be due to lack of clever technology and R. & D.-based ideas for treating water. The failures will come from an inability to produce and deliver ideas and technology in a temporal-economic mode that the market will accept. Clever means of removing pollutants from water, based on good physics, chemistry, and biology (which many of the current products and services in this market incorporate) do not make a sustainable business if the embodiment of these clever technology ideas is in poorly designed, tooled, engineered, and produced products and services that fail in the factory, the account books, the marketplace, or the user's plant. The specific case investigated was overloaded with R. & D. talent and very short indeed of people who embodied necessary IT skills and capabilities.

Although people from particular economic schools may view such shake-outs as merely one of the necessary side effects of a free market system, they involve tremendous wastes and misapplications of scarce resources—people, time, money, materials, and energy (both physical and psychic). Such losses should be segregated in the national accounts as "losses due to innovation" or, perhaps, "losses due to inadequate innovation capabilities."

In some of our studies of adoption of new technology by U.S. industry (let alone studies of technology adoption by LDC's) the lack of adequate IT related to installing, adapting, using, maintaining, and improving capital equipment has been brought home countless times. For example, the delivery to a user of a new numerically controlled machine tool, which is thought of by some analysts as the culmination of the innovation process, is actually only another process stage in getting a new concept and technology from the R. & D. or engineering laboratory into routine use. Our detailed, "micro-dynamic" studies of such introductions into users' plants (Ettlie and Rubenstein, 78/65) clearly illustrate the role of IT in integrating the new equipment or technology into the techno-economic-social matrix of production in the user firm and the many barriers that must be overcome.

2.2 IT's Crucial Role in the Innovation Process Has Not Been Adequately Recognized by Top Managers and Policymakers

The main point in the previous subsection is that R. & D. alone is not *sufficient* for producing innovations and assuring their application or implementation. The many other factors under the heading of IT (see section 1.1) are necessary to each stage of the overall process. If there were a choice between support only for R. & D. or IT, a good argument could be made that an adequate range of ITs without much formal R. & D. could keep us going more effectively in the short (and perhaps intermediate) run than increased R. & D. without broad and deep IT capabilities. In the longer run, of course, our technological barrel, from which many ITs are refilled continually, would empty; without a vigorous and adequate level of R. & D. our productive and competitive systems would eventually fail.

This short run-long run threshold varies greatly among industries and sectors. In military and electronic technology the cross-over point may occur (and frequently does) in months, while in others the rate of significant technological change is so slow that a company, industry, or country can coast for decades on applications of old technology through clever use of IT.

The main point in this sub-section is that many top managers in government and industry and policymakers in all sectors do not recognize this situation or, if they recognize it in abstract, do not feel that they can or should do much about it. It is relatively easy to decide to set up or dismantle R. & D. programs, laboratories, or projects because they are so distinct and visible. The response and recovery time lags in making these changes have their own penalties, but at least decisionmakers feel that they can manipulated the organizations, projects, and budgets representing formal R. & D. programs. They are much less comfortable with the nebulous, uiquitous and sometimes arcane entities which embody IT. How many economists, political scientists, legislators, lawyers, or bankers without direct "hands-on" experience in the factory have any feeling for what is involved in developing capabilities in such apparently mundane fields as: welding, forging, quality control, patternmaking, coating, lubrication, and heat treatment.

Except through literature and other art forms which depict the apprenticeship process and the years it takes to train a craftsperson, few nonmanufacturing or engineering decisionmakers know of the tremendous investment U.S. (and all other) industry has in such people and how long it takes to build teams needed to provide the necessary IT parts of the innovation process, as well as the routine production process. These non-glamorous areas receive little top management attention and virtually none from public policymakers except when a brief flurry of concern is expressed for a specific industry sector which is threatened by foreign competition.

At the point when such flurries occur, it is often too late to do much about the technological base of the industry, which may have eroded both at the upstream (R. & D.) end of the innovation process as well as the many impact points for IT all along the chain. As a strong advocate for decades of the need to maintain and strengthen our formal R. & D. capabilities, I cannot take the position that IT capabilities should be developed, maintained, and expanded at the expense of R. & D. However, I have been concerned, however, that too much attention of policymakers and top managers has been focussed on the glamorous "front end" of the R. & D./Innovation process and that a proper balance needs to be achieved to protect our overall innovative capabilities. This imbalance is starkly illustrated by the situation in a multi-billion dollar U.S. manufacturing company where only one member of corporate top management had any appreciation of the fact that the company's productivity and economic base was being eroded over a period of years by neglect of manufacturing capabilities, facilities, and equipment. Finally, he was able to convince a new chief executive officer of the need for emergency injection of capital funds in this direction, after it became clear that the company was losing its market position and profit margins through neglect of IT and its manifestations in equipment, facilities, and human resources.

2.3 *Effective IT Can Make a Crucial Difference in U.S. Ability To Compete in Both Domestic and International Markets*

The United States still maintains a technological and commercial lead in many high technology markets such as aircraft, computers, military hardware, and some scientific instruments. It has been losing ground in other product lines and markets where high science or "breakthrough" technology is not common, however, and where product features and price dominate market share. In this latter case, clever design, human engineering, low cost manufacturing methods and tooling, easy maintainability, reliability, serviceability, and other "non-scientific" aspects of a product influence success in the international competitive market. Because some Japanese products have features not matched by any U.S. products, and in spite of higher prices, Americans buy many high-technology products from Japan. Few of these features appear to be the product of high level R. & D., but appear to have the advantages which come from competent engineering and design, after the formal R. & D. on the product has been done.

Despite their preferences for U.S. made production equipment, many U.S. manufacturers are turning increasingly to foreign original equipment makers (OEMs) to buy machinery that may not have a significant price advantage, but which has features and delivery times that they need. Further, some of the purchasers feel that they can depend more on follow-up service, warranty, and spare parts from some foreign OEMs, despite the geographical distances, than they can from some domestic producers.

International technological competitiveness has been a major issue between the United States and other countries for some time, swinging between the extremes of "technological gap", "technological imperialism by U.S.-based MNCs", to "export of jobs" and the "Japanese or Asian menace" to many of our basic industries. I have no intention of offering a single factor explanation of the deteriorating competitive position of many U.S. products in the world market (including our own domestic market, where U.S. and foreign products meet head to head), let alone attribute specific or general declines in our competitive position to superior IT capabilities of our competitors. It is quite possible that erosion of some of our non-R. & D. technological capabilities are contributing to this situation, however.

One clue to this economic threat to the United States is the situation we find in our work in some of the LDCs where U.S. MNCs have subsidiaries or branches. Although the U.S. system of "technology transfer" has developed to a high degree and although product and process standardization are almost a religion, many of these standards—both in ways of doing things and the resulting products deviate significantly from the States-side equivalents. This can be largely attributed to the lack of certain IT capabilities in the LDC plants and, by inference, to the lack of sufficient depth in those particular capabilities in the parent organization to provide assistance to the remote plants.

We have even observed the difficulty of transferring certain IT skills internally between domestic operating divisions or between corporate engineering/manufacturing staffs and operating divisions or plants. This is easily understood, once we get beyond the textbook or polemic definitions of technology transfer and begin to understand the tedious, time-consuming, nitty gritty aspects of actually transferring the skills needed to transfer technology from one place, group, company or country to another, and the compounding of the transfer problems by cultural, social, and psychological factors. Our work in international technology transfer, for example, has yielded many lists of barriers to what sometimes appear to be simple transactions which both parties to a technology transfer agreement appear to want to consummate.

Such barriers were identified at the meeting of the United Nations Economic Commission for Europe in Geneva, July 1975, whose topic was "The Management of the Transfer of Technology within Industrial Co-operation." An abstract of these issues from papers and discussions presented by representatives of a dozen U.S. corporations and their West and East European counterparts (Rubenstein 1976) shows these potential barriers:

1. Cultural differences among sources and recipient countries.
2. Appropriateness to recipient of technology proposed for transfer.
3. Local conditions and recipient characteristics affecting productivity.
4. Extent of training associated with the transfer.
5. People-dependent nature of technology transfer.
6. Transfer depends on recipient's technical competence.
7. Differences between source and recipient in standards, components and materials.
8. Need to study thoroughly partner's technology and methods of operation.
9. Preference of many Western companies for limited agreements.
10. Is pricing to be based on cost or value?
11. Selling products versus selling technology.
12. Differing concepts of profit.
13. Role of capital costs in the transfer.
14. Need for mutual benefits to both partners.
15. Buy back and barter versus cash payments.
16. Protection of source's R. & D. investment over a long period.
17. Role of intermediate organizations such as agents and trading companies.
18. Absence of common commercial traditions.
19. Theory versus practice in technology transfer.
20. Transfer is more complex than just licensing.
21. Unbundling of software from hardware.
22. Start-up technology is needed and often not written down, and is people-dependent.
23. Ability of recipient to shop around for alternative source companies.
24. Means of payment for technology.
25. Rights of recipient to re-license third parties.
26. Differences in internal structure of source and recipient countries (organizational, political, and economic).

3. Some Examples of Imbedded Technology (IT)

3.1 Supporting Infrastructure for R. & D.

One traditional supporting technology in the "wet processes" (chemistry, biology) is often listed as glass blowing. In the mechanical industries, model making or drawing (creative drawing, that is, rather than mere drafting and detailing) are key ITs. In electronics, basic supporting ITs vary, but breadboarding, maskmaking, wiring, instrument modification, have played prominent roles. Of course, some of these and many other ITs have been made obsolete (at least theoretically and for the future) by machines that perform many of the tasks that skilled artisans and technicians performed traditionally and by computer systems that can "outdraw" and "outvisualize"—when supported by holography—the artists that often went under the unromantic job titles of draftsmen.

Such IT capabilities in the R. & D. process are only part of the story, however, and too much focusing on them can distract attention from the many other not-so-obvious skills and capabilities that are often shared by "professionals" (university graduates or, in some industries, advanced degree people) and technicians. Some examples include crystal growing, cryogenics, heat treating, welding, making biological cultures quickly and "cleanly", and removing as much of the "noise" as possible from the pictures achieved through electron microscopy by almost fanatic maintenance and cleanliness of the equipment.

In some labs in some companies in some industries, the work of technicians in performing some of the tasks implied by these IT specialties and the products of these ITs are considered more important for the day-to-day maintenance of the products and processes for which R. & D. is responsible than academic theories or scientific experimentation.

This does not imply that all functions that are performed by technicians (e.g., animal care, cleaning up experimental equipment, taking routine data) are to be included in the concept of IT and focused on as critical to our innovative capabilities as a Nation (although some people might take that position). Many of the technical chores performed in our R. & D. laboratories, which are performed by technicians, are not the product of university education, are not found in the scientific and technical literature, and are in danger of costing us dearly as the number and quality of skilled practitioners decline. The dropping of a lot of the traditional laboratory "arts" from science and engineering curricula over the past two to three decades suggests that their importance may not be recognized by the academic community and the failure to train adequate numbers and levels of people to perform them in industry suggests that their importance may not be recognized by many of the managers of organizations that do R. & D.

There are two particular ITs which represent a wide range of knowledge, skills, capabilities, and behavioral implications. One is a single action done by a single engineer engaged in development of an engine. This example was suggested by an incident encountered recently in a company developing engines where a manager asked one of the engineers "did you torque the engine", and received a blank start. The situation involved a fine art which required a "feeling" for the amount of torque placed on the engine in adjusting it and about which no manual could be written to communicate that feel. Perhaps a parallel is the "learn by doing" technique used in medical school when the preceptor tries to teach the medical student how to listen to a heartbeat.

The other example is at a downstream phase of the R. & D. process and involves "start up" know-how, also involving a whole series of "feelings" and "judgments" as to whether things are "going right" or are likely to fail or explode. Although this is often looked upon as part of the manufacturing responsibility, it is a necessary part of successful innovation for new processes and the products they are intended to produce. Many projects (products or processes) which are considered successful by R. & D. fail miserably in the start-up phase through unexpected costs, delays, material wastage, equipment breakdowns, extended learning time for operators, below quality production, and other undesirable effects. Some of these problems and failures may be due to poor original design. Others are due to specific mistakes by start-up people (typically engineers, supported by manufacturing people or vice versa). Still others are due to lack of experience with or attention to the specific characteristics of the new product or process being started up.

3.2 Manufacturing Technology

Probably, if a "complete" list of important ITs were compiled which might make a major difference in our national productivity, costs, product quality, international technological competitiveness, and other factors, those related to manufacturing might dominate the list. When we focus on factors contributing to the ultimate success of technological innovations, such ITs in manufacturing might also figure prominently.

A number of manufacturing ITs related to the "downstream" phases of the overall R. & D./Innovation process has been mentioned in earlier sections of this paper and will be mentioned in following ones. Again, without attempting an enumeration or a taxonomy, here are some examples which appear important in the downstream parts of R. & D./I that involve manufacturing.

Automation.
Coating.
Computer-aided manufacturing.
Control systems.
Corrosion.
Cost control.
Design review.
Forging.
Foundry techniques.
Heat treating.
Heating and ventilating.
Inventory control.
Lubrication
Machine design.
Materials handling.
Materials management.
Metrology.
Nondestructive testing.
Packaging.
Plant construction.
Plastic molding.
Pollution control.

Quality control.
Reliability.
Robotics.
Standards development.
Tool and die making.
Welding.

Some of these IT's are imbedded in the experience or skills of one individual in many plants and companies. Others are represented by a formal group or an informal aggregation of individual skills into an organizational capability. Some of them are embodied in college graduates, such as scientists (rare, except in some fields) as engineers who work in individual plants or corporate manufacturing staffs. And still others, perhaps the majority, involve technicians (non-graduates) either working alone or supporting engineers or scientists.

One situation that is not uncommon in R. & D.-performing companies, is that the particular individuals or small groups which embody these kinds of IT's are the subject of intense competition among individual plants, R. & D., and other corporate staffs. A recent shift of a half a dozen control metallurgists from corporate R. & D. to plant engineering in a local company left R. & D. short of such talent and did not fully satisfy either the needs of the plants who received them (because the former R. & D. metallurgists were not considered practical and experienced) or the individuals themselves (because of their removal from their preferred career paths and the low level of use the plant managers made of their technical talents).

3.3 Other IT

There are many other skills, capabilities, and bits of know-how that contribute to successful innovation in the industrial firm. Some of them can hardly be called "technological" in the sense that they are based upon science or "hard" technology. They are as essential to success in innovation as many of the IT's mentioned under R. & D. and manufacturing, however. Some of them, in fact, are management functions which, when associated with the R. & D./Innovation process, can become highly specialized.

Among this set of ITs, procurement/acquisition (terminology varies in the field) and contract administration loom large for many programs and projects. Getting the right materials from the right sources at the right price and time and according to requirements can make the difference between successful and unsuccessful innovation. This is particularly true where value added is a small percentage of total product cost and most of the cost represents purchased materials, components, equipment, and services. The not infrequent conflict between R. & D. and purchasing people can be quite destructive of the time, cost, or quality performance on a project for an innovative product. Therefore, many organizations pay particular attention to recruiting, training, and maintaining an effective procurement staff specializing in support of R. & D./Innovation. Contract administration and all that it implies for meeting cost and schedule targets is also a key element in successful innovation. In some contexts, contract administration either includes or ties into project management and related functions.

Although the formal, legal aspects of patent management (writing up, searching, filing, appealing, litigation, and licensing) are often handled by legal staff, at least in large companies, there are other elements of patent management which are more subtle and which might fall into the category of IT. These have to do with the intuitive, experienced-based aspects of patent management, such as searching for patentable items, knowing how to encourage people to disclose and file and follow up, sorting out the wheat from the chaff, and other intangibles that are hard to codify and teach in law school.

Although some of these management skills appear to stretch the "technological" connotation of "imbedded technology," they figure prominently in the actual transfer of technology among countries and companies and even within companies. For example, while this section was being written, a group of us engaged in a series of field experiments on "key communicators in R. & D.," visited one of our field sites to discuss experimental treatments for one aspect of their R. & D./Innovation process—the licensing or sale of technology. This very large company had compiled a list of approximately 100 items of know-how, process technology, and other items which were not proprietary mainstream products and management had been exploring the possibility of selling, licensing, or otherwise making money on some of this technology. When their explorations yielded the fact that most of the potentially profitable technology exchanges would require substantial involvement of their own people, including managers, for extended periods, they decided to shelve the whole idea.

Few transfers of technology beyond simple provisions of new parts or equipment embodying changes can be completed by "mail" or by "arms length" exchanges. They generally require "hands on" instruction and cooperation in installation, start up, breaking in, adapting, improving training for use and maintenance, and going through the other activities that are required for effective and "full" transfer of technology. Given this situation, many of the "softer" ITs play prominent roles in the transfer aspects of the overall R. & D./Innovation process, whether within a given company or across companies and national boundaries.

4. What Indicators Can Be Used To Measure and Monitor Imbedded Technology (IT)?

4.1 Introduction

For several years a small group of colleagues and I have been exploring the possibilities and problems of identifying and using indicators for monitoring and evaluating the many stages of the overall R. & D./Innovation process, guided by the general flow model of figure 1, which is described in section 1.2. As indicated in that section, we have used this to locate and identify barriers and facilitators to the R&D/I process at various stages as it progresses from laboratory to application. (*Note*: Although the "usual" flow of events for a new or significantly improved product or process generally involves the sequence of activities depicted in the model—R. & D., transformations, implementation—many pieces of technology do not originate in formal R. & D. programs or laboratories and many of them involve later starting points and cycling back through R. & D. at later stages of development when technical problems arise that "downstream inventors" cannot resolve without formal R. & D. inputs.)

In our work on R. & D./I indicators, particular attention has been paid to mainstream variables and entities involved in the flow of a project or program. In the course of these explorations, however, we have encountered many potential indicators and measures for the less obvious aspects of the R. & D./I process which come under the heading of IT. As an illustration of this "spin-off" of our indicators work, figure 2, presents some examples from a recent study of indicators for small business R. & D. capabilities (Geisler, Rubenstein, Thompson, 78/4).

In general, the process of identifying, measuring, and monitoring or evaluating IT's as both capability and output (ideas, knowledge, techniques) indicators for the R. & D./Innovation process is much more difficult than the kinds of measures of mainstream R. & D. currently included in the National Science Board's "Science Indicator" series. Aside from the usual problems of surveying large numbers of companies and getting reliable data that already exists, measuring IT's has added complications. Few companies have any records that directly reflect the kind of indicators needed to assess IT's. In addition, few managers think of their non-R. & D. resources involved in the overall R. & D./Innovation process in separable terms that would lend themselves to identifying and measuring indicators for IT. For example, of the people and knowledge in the company devoted to welding or foundry operations (in many cases hundreds of people and multiple facilities) only a small proportion are relevant to the success of new or significantly improved products or processes which are generally identified as innovations. An attempt to identify such R. C D./I-related ITs would require a new approach to "human resources accounting"—a function that is growing in industry, but slowly.

Despite these difficulties, efforts should be made to include indicators of IT in the measurement of national resource inputs for R. & D./Innovation and for assessing the outputs of that process. The rationale is not mere "tidiness" in the sense that our current national accounts are far from complete in representing the R. & D./I process, but the practical purpose of policymaking aimed at maintaining and improving these valuable technological assets.

4.2 Use of IT Indicators by Government Procurement People, Company Management, and Federal Policymakers

Given that a manageable set of indicators for IT can be developed and that credible data can be gathered on them on a regular basis, then what use can be made of them for what purposes? Although, as in the case of many indicators, new uses may emerge after they are developed, there are several immediate needs that come to mind and three groups of potential users have been selected to illustrate the possibilities. Usage by the third group—Federal policymakers (in the legislative and executive branches) is discussed in more detail in section 5 of this paper on public policy implications of IT. The three illustrative user groups and possible uses to which they might put IT indicators are:

(*a*) *Procurement people.*—Currently there is increasing interest in the Department of Defense, the largest Federal purchaser of technological products and services, in a concept called "Past Performance" which has been used in procurement for many years in widely varying ways and under different names. It involves an attempt to provide indicators of contractor capabilities in a number of key areas as aids in: selecting contractors for a particular project or program; and monitoring performance once a contract has been awarded. Possible applications to these two important functions are given in figure 3.

(*b*) *Company management.*—There are many uses to which an alert company management might put improved indicators of their IT resources. An important one is in maintaining its technological capabilities through recruitment, training, upgrading, and replacement of people with important and scarce IT skills. Another is in maintaining an adequate capability level-in critical IT's and forecasting or anticipating threats to that capability from turnover, promotions, cutbacks, transfers, retirements, mergers and acquisitions, obsolescence, or inadequate support (funds, facilities, equipment, supplies, and services).

The kinds of lessons learned by the two companies discussed earlier—the cases of forced abandonment of a technical venture due, in part, to inadequate IT and the unexpected loss of key IT capabilities through early retirements—might serve as motivators to many managers to pay more attention to IT's than they currently do. One technique which made a stir some years ago, but which has made little headway in industry recently, might be revived in the context of IT. This is the "skills inventory" of important technical skills—R. & D. and other—that is represented by the company's current work force. The lack of adoption and wide-spread use of this technique is due to cost and the political fallout from gathering and maintenance such information beyond the superficial level of merely listing (in files or on a computer) education, previous job titles, and, in some cases, formal assignments in the company.

Most of the attempts at such skill inventories did not include the depth of information needed for a true skills inventory even for R. & D., let lone for IT and the overall R. & D./Innovation proces. It may be worthwhile for company managements to reexamine the costs-benefits of such an information system for forecasting, deploying, and maintaining its technological human resources.

(*c*) *Federal policymakers.*—Although specific public policy implications are discussed in more detail in the next section, brief examples are given here of some possible uses of IT indicators by legislators and executive agency policymakers (in addition to the uses in the procurement/acquisition process). Perhaps one of the major kinds of policy actions which the Federal Government might take with respect to ITs is in the training area to be sure that the supply and quality of such national assets are at proper levels. Another key area involves the exportation of know-how and other manifestations of IT through technology transfer and technical assistance agreements. A third might involve specific incentive programs to enhance IT development in industrial firms and throughout the supporting infrastructure (consulting firms, and trade association technical assistance and R. & D. organizations). Finally, the Federal Government, which is already doing a great deal in the area of dissemination of IT information (notably through mechanisms such as NASA's Technology Utilization Program, described in several of the references in sec. 7) might do even more of this to enhance industry's IT resources.

5. Some Public Policy Implications of Imbedded Technology and Some Suggestions for Action

5.1 Introduction

In this paper I have undertaken to explore possible policy options for the Federal Government with respect to IT and develop some approaches that might lead to specific policy options. Consistent with this objective I present, in figure 4, some suggested actions which the legislative and Executive branches of the Federal Government might undertake to enhance the U.S. posture with respect to IT. Although many of these suggestions appear reasonable and feasible to me, each requires careful analysis and experimental evaluation before it is put into practice or recommended for legislative or executive action. The reason for this caution is that many programs intended to provide incentives to the innovation process in the United States and other countries have fallen flat because they were not carefully designed, tested, evaluated, and adapted to the specific circumstances involved (differences between: industries, countries, companies, technologies, and people involved in the R.&D./I process).

The actions in figure 4 can be grouped into approximately five more general categories which are nothing more than a convenience for discussion purposes, since almost all cut across technical fields and legislative committee or executive agency jurisdictions. In no sense are the items of figure 4 and the categories below intended as a complete or comprehensive program of government incentives to innovation. There have been and currently are dozens of such lists being drawn up in connection with the several waves of activities on the status of technological innovation since the early 1970's and the continuing programs of such organizations as NSF, NASA, Departments of Defense and Commerce, other executive agencies. Office of Technology Assessment, (OTA), and the Joint Economic Committee (JEC). Most lists are redundant and brand new ideas are rare. What is also rare are systematic and credible evaluation and application of some of these ideas—e.g., some of the frequently cited incentives to innovation. That is the big gap that needs to be filled in the R. & D./I policy area, including that part related to IT's.

Two more figures address the requirements for and difficulties of actually influencing the R. & D./Innovation process through government action. Figure 5 is a simplified version of a general model of government influence on the R. & D./I process which has been used to guide a recent series of case studies of innovation in the automotive industry (Rubenstein and Ettlie, 1979). Figure 6 is a more generalized version of that model for a series of studies of industrial management responses to government incentives for innovation in half a dozen countries. (Rubenstein et al, 75/95, and Watkins et al 76/9).

Figure 5 emphasizes what the government can possibly do to influence the behavior of firms with respect to innovation. Figure 6 focuses on the long tortuous path between formulation of a government incentive or regulation related to the innovation process and the many informational, perceptual, and behavioral stages that must occur if the incentive/regulation is to have a beneficial impact. It is not an optimistic picture, and deliberately so, since the influence process is far from direct or simple. The multi-country studies guided by this second model focused on the "information-perception-evaluation" stages (boxes 2, 3, and 4) which precede any significant decisions or commitments of resources to actual innovation projects as a consequence of government action.

5.2 Government's Role in Training for IT

Below the university level, government (federal, state, and local) dominates the educational and training system in this country. Even at the university level, in addition to direct influence through state universities and colleges, government has a number of ways of influencing educational content and method throughout the system via such mechanisms as research and training grants.

These methods of influence might be used to focus attention on the need for more and better training in the arts included under IT; toward the establishment, improvement, and stable maintenance of those programs specifically aimed at particular IT skills; and for provision of direct support for such programs. In addition to attempting to influence the educational sector directly, government agencies might provide direct training facilities through the many government laboratories and other technologically based facilities they operate.

This is not a plea for still another "title X" of an education act addressed to still another special interest group. Rather it is a suggestion that the status of our educational and training institutions be examined in the light of IT needs for the future and that influence be brought to bear, through a number of means including direct funding, to assure adequate attention to this necessary and important area of skills. Although it is true that many (perhaps most) individual "skill ITs" need to be imbedded in people's heads and hands over long periods (decades for some skills), an early start in secondary school or early in the college years could point many people in that direction and provide them with a career focus they might have been unaware of or misinformed about.

Because of the very nature of skill acquisition—the time lags, the role of motivation, the need for practice, and the need for face-to-face, hands-on instruction—I am not suggesting more "orientation courses" which, through brief lectures, demonstrations, or films, try to catch the imagination of students and then drop them at that point with no way to follow up and get rigorous training. Some critics suggest that such brief and superficial exposures of medical students to non-mainline specialties such as nutrition, gynecology, tropical diseases, or psychiatry can do more harm than good in preparing non-specialists to cope with serious problems in those areas.

5.3 Potential Incentives for Stimulating IT

The general field of incentives for stimulating overall technological innovation has been and is currently being plowed extensively and it is unlikely that many radically new ideas will spring out of the many committees and study papers (including this one) which are being written. The big gap is, as mentioned above, in the many painstaking steps required to implement them, evaluate their impact, and improve them.

Several of the incentives regularly touted for innovation in general—e.g., tax reforms, cost sharing, cooperative research, reduced regulation, direct subsidies—might have an impact on stimulation and development of IT. Several other countries have been offering incentives (often not even identified as such) and programs/facilities for the development of the kinds of IT skills and capabilities listed in section 3.2. Not much is known in this country about the details of such incentives, despite our several surveys of incentives to technological innovation (e.g., Rubenstein et al., 75/95; Watkins et al., 76/9; Allen et al., 1978; Pavitt et al., 1976) because of our focus on the mainline aspect of technological innovation, especially the upstream aspects (R. & D.).

Many people are calling for a review of such incentive schemes in general, and attention should be paid to those that might influence IT's. I believe that a much better result may be achieved through some attention to stimulating IT's through incentives as compared to concentrating only on mainline R. & D. aspects of the R. & D./I process.

5.4 *Exporting Technical Know-How*

This is a complex problem and is not receiving adequate attention viz-a-viz exploration of actual hardware—e.g., computers and defense-oriented equipment. In this context, including, below, are some comments prepared for the National Security Affairs Conference, July 1976 (Rubenstein 76/43) in which I pointed out some of the practical aspects of attempting to control the flow of "technical know-how" overseas.

SOME ISSUES RELATED TO CONTROL OF INTERNATIONAL TECHNOLOGY TRANSFER (ITT)

(1) How can firms outside the main stream of the defense business be informed and convinced of the importance of clearing "know-how" and other informal ITT transactions with the Department of Defense (DOD) and the Department of Commerce (DOC). This involves a difficult detection problem for the cognizant agency or agencies which do not have a prior relationship with strictly or primarily commercial firms. The objectives of protecting potential sensitive or strategic technology may conflict with the firms' objectives of carrying on a profitable trade in high technology. If, then, there is a significant amount of design or manufacturing know-how now being or likely to be transferred by firms outside the current orbit of DOD contracts and relationships, there is likely to be reluctance on the part of the commercial firms to cooperate, without significant incentives or penalties.

(2) How can critical technology be protected when third parties are involved. Once trade secrets are out of the bag there is no putting them back. A few minutes' observation of a "secret" process by a sophisticated observer can render some trade secrets forever open. Unless third party countries and their plants are sealed (actually or

figuratively) there is little protection against leakage of know-how information that can be transferred by a glance, a conversation, or some observation. For know-how information which requires training, there would have to be a reversal of the trend in some sectors of the movement of skilled people between countries. In some industries the job market is international. As the British learned during the industrial revolution, when people move around, know-how can move with them, despite the embargo on export of machines or even drawings. The shifting nature of international relations and alliances makes it unlikely that selling only to our "friends" is protection against loss to a third country which may be an antagonist at any given time. Certainly Draconian measures can be attempted to shut off flows to and from third countries, but the question of cost in diplomatic, economic, and human terms may be too high to justify them.

(3) If an attempt were made to extend formal controls to the less formal modes of technology transfer (e.g., through consultants, visits, conferences, international task forces and missions—such as those of the U.N. agencies and development banks) what kind of measures would be needed to delineate and control the specific kinds of information that is embargoed? Would the cognizant agency—e.g., DOD or DOC have to place inspectors in the plants and offices of private, non-defense companies, universities, and other non-defense institutions which deal with technology that meet the test of being critical? Would the travel of U.S. citizens not engaged in militarily classified work be restricted on the basis of the potential future strategic potential of their knowledge? How could this be justified, if it appeared desirable to do so, in a free society that is not at war? Of course this issue has been with us for many years and it has been addressed in a number of ways, but perhaps never before in a social climate such as that existing post-Vietnam and post-Watergate.

(4) How can sellers of technological equipment and know-how be compensated for the loss (or perceived loss) of not only the immediate sale of equipment, a process, a product line or some know-how, but future potential market share that might follow. Frequently, the provision or promise to provide some new high technology is the sweetener that gives a U.S. manufacturer a competitive advantage over firms in other countries. Can the value of such losses or opportunity costs be calculated and somehow added into the cost/benefit equation governing the decision on what specific areas of technology to restrict?

(5) What kind of methodology would be needed to detect accurately the presence of some critical technology imbedded in a product, process, machine, or material—e.g., a new alloy or alloying process, a new method of packaging a circuit, a sophisticated method of chemical or biological analysis, or a new method of heat treating or material removal or joining?

(6) Can a Federal agency or agencies devise better means of protecting proprietary know-how than commercial firms now have, when the firms' future existence may be threatened by a loss of competitive position? How much tighter security is feasible in an open society than is now already practiced in many highly competitive industries—both domestic and international? A major method of such protection depends on a combination of loyalty to the company and material

incentives rather than on the older threats of blacklisting in a closed industry. Can the Federal Government provide more protection than is now offered by commercial firms in their own self interest, without incurring unacceptable social costs?

5.5 Role of Government R. & D. in IT for Industry

As in the case of incentives for innovation and export policy, most attention has been focused on dramatic achievements and mainline R. & D. products when considering "technology transfer", "technology utilization", or "spin off" from Federal R. &. D. programs. Several articles listed in section 7 describe NASA, DOD, and CERN (the European Nuclear Reactor Center in Geneva) contributions of this nature. They also include additional kinds of outputs, many of which are clearly IT's in the context of this paper. The difficulty has been that this attempted transfer has occurred (or been attempted) primarily on paper, rather than by people. A major theme of this paper and other work on technology and skill transfer is that effective transfers occur primarily through people—either actual movement of people from one location to another, or intensive and continuous communication between "sources" and "users". This is particularly true for IT, which is not covered well in textbooks, patents, the Scientific and Technical Literature (STI) or other formal channels.

Although several Federal agencies, notably NASA and DOD, have had long standing policies of encouraging dissemination of such information, these policies have often amounted to lip service and have included little access to people in Federal laboratories as compared to paper (technical reports and summaries).

My general suggestion is that these and other agencies review the actual behavioral patterns associated with such transfer activities and attempt to shift the emphasis from paper to people. This will require more actual access to Federal labs for cooperative work, detailed demonstration, intensive training, and other modes of IT skill transfer through people.

5.6 Dissemination of IT Techniques and Information

Finally, improved methods should be sought for the focusing of attention on IT, the extraction and dissemination of information about it, research and experimentation on it, and other forms of communication which are generally used for mainline R. & D. (conferences, seminars, demonstration projects, and special handbooks and manuals). Figure 4 contains some specific suggestions in this direction.

6. Some Suggestions for Further Analysis

6.1 Obtaining Survey Data and Identifying Examples of IT

The National Science Foundation should expand its definition of R. & D. used in its annual and other periodic surveys which feed into Science Indicators and other reports that describe the state of R. & D. to include many of the skills, capabilities, assets and outputs of IT. There is likely, of course, to be an outcry from the industrial firms which will be asked to furnish this additional information, on top of all the other information they are asked for in connection with their R. & D. and other activities. An off-setting incentive that can be offered in response to this likely complaint is that the firm itself will benefit from systematic data on an important innovation-related area of the firm which few of them have much formal knowledge about. An additional incentive might be an offer to provide technical assistance, grants, or other help for the initial survey. It is not likely that "smooth" quantitative data such as that which appears in the NSF surveys of R. & D. will be forthcoming in connection with IT. There are too many definitional, detection, imputation, and other technical problems to guarantee that. This means that perhaps the best that can be expected (and of potentially high utility) is a combination of some quantitative data and some descriptive data in the form of case studies or other modes of presentation which convey the essence of the IT situation to policymakers and managers—the general level and quality; the accomplishments through IT; the limitations; the need for policy and managerial action to develop, improve, and maintain our capabilities in this important area.

6.2 Tracing the Origins and Impacts of IT

If sufficient leads can be obtained from the suggested expansion of the NSF surveys, or if another agency or organization undertakes to assess the status of IT in industry, a number of policy-oriented results might be achieved in relation to the health of the Nation's R. & D./Innovation process. These results might be of two kinds—tracing ITs to their origins and tracing their social and economic impact on various sectors.

In the first case, the tracing of ITs to the government labs or other sources can provide a basis for the kinds of changes in Federal practices with respect to technology transfer from government laboratories and programs discussed in section 5.5. It can demonstrate the potential value of increased "openness" of Federal R. & D. facilities and programs to industry.

In the second case, tracing "downstream" can provide evidence for the importance of ITs in the overall R. & D./Innovation process and guide policies consonant with that importance.

7. Selected References to Material on Imbedded Technology and Related Subjects

As mentioned at the beginning of this paper, there was no intention of doing a state-of-the-art literature search. The items referenced below, however, provide further insight into and detail on many of the issues discussed in the paper. They are presented here for further reading by policymakers and further analysis by researchers. The sample of material is rather eclectic, although there is a heavy representation of reports on the NASA Technology Utilization program. Of all programs by Federal agencies to provide technological inputs to industry, NASA's has been one of the most intensive and extensive and the best publicized. The small number of references to programs and specific contributions of other agencies should not be taken, however, as a measure of their activity in the field of imbedded technology and related matters since no statistical sampling was involved. It may be an indication, however, of the low profile that many of them maintain in this field. Included in this list of references are some of the POMRAD [4] papers cited in the text.

Abernathy, William J., and Utterback, James M. "Patterns of Industrial Innovation." *Technology Review*, Vol. 80, No. 7, June 1978.

A model of the changing emphasis of R&D/Innovation in the firm as its products and processes mature.

Allen, Utterback, Sirbu, Ashford, and Hollomon, "Government Influence on the Process of Innovation in Europe and Japan," *Research Policy*, Vol. 7, No. 2, April 1978.

A multi-country study of incentives to innovation conducted by M.I.T.

Anuskiewicz, Todd. *Federal Technology Transfer*. Prepared for National Science Foundation Office of Intergovernmental Science and Research Utilization. The George Washington University, Washington, D.C., August 1973.

Summaries of technology transfer activities done by each of 14 U.S. Government agencies and foundations, including numerous examples of technology transfer from the public to private sector.

Ashburn, Anderson. "How to Lead in Innovation." Editorial, *American Machinist*, September 1978.

An editorial on the role of automation in productivity.

Baloff, Nicholas. "Startup Management." *IEEE Transactions on Engineering Management*, Vol. EM-17, No. 4, November 1970, pp. 132–141.

Discussion of learning curves and startup models in several fields of technology.

Business Week. "Metal Casting the Soviet Way." *Business Week*, August 7, 1978, p. 60 D.

A news item about a new Soviet technology not yet used outside the U.S.S.R.

Centre for the Study of Industrial Innovation. *Aspects of Spin-off, A Study of the Concorde and the Advanced Passenger Train on Their Supplier Firms*. London, England, October 1971.

A British study of the incidental effects which large advanced projects can have on their sub-contractors and suppliers.

Coddington, Dean G., Bortz, Paul I., Freeman, James G. *PATT: Project for the Analysis of Technology Transfer*. Denver Research Institute, Industrial Economics Division, University of Denver, March 1970.

Private corporations tend to minimize benefits they receive from Federal research (p. vii). Hypotheses about technology transfer (pp. 1–2). Conclusions on improvement of technology transfer (pp. 4–5). Some case studies of transfer to industrial sectors are contained in Appendix A.

Davis, Ruth M. "Quantity a Key to Military Strength." Address at Elgin Air Force Base, excerpted in *Science*, Vol. 200, June 9, 1978, p. 1134.

A note on the role of quantity production in technological superiority.

Denver Research Institute. *Space Benefits: The Secondary Application of Aerospace Technology in Other Sectors of the Economy*. Program for Transfer Research and Impact Studies, Industrial Economics Division, Denver Research Institute, University of Denver, January 1978.

A source of case studies of technology transfer from NASA's R&D. Cases are listed by type and there is also a listing of organizations which have been beneficiaries of NASA technology transfer.

Dun's Review. "Productivity Plays: Growth Stocks for the 1980s." *Dun's Review*, November 1978, pp. 125–128.

Discussion of financial viewpoint of investments in companies which are in the "productivity business" via labor saving equipment and systems.

Ettlie, John E., and Rubenstein, A. H. "Social Learning Theory and the Technology Transfer Process." Department of Management, College of Commerce, DePaul University, Chicago, and Department of Industrial Engineering and

[4] Program of Research on the Management of Research and Development at Northwestern University.

Management Sciences, Northwestern University, Evanston, Ill., October 1978. Doc. No. 78/65.[5]

Some of the theory underlining the attempts by industrial users to adopt numerically controlled machine tools.

Federal Council for Science and Technology. *Directory of Federal Technology Transfer*. Committee on Domestic Technology Transfer, Executive Office of the President, Washington, D.C., June 1975.

For each of several agencies of the U.S. Government, a listing of technology transfer policy and objectives; technology transfer utilization responsibilities; method of implementing technology transfer; technology accomplishments.

Geisler, Eliezer, Rubenstein, A. H., and Thompson, C. W. N. "A Method of Assessing the Technical and Innovative Capabilities of Small Businesses." *Proceedings of the Seventh Annual Department of Defense Procurement/Acquisition Research Symposium*, Hershey, Pa., May 31-June 2, 1978, pp. 196–200. Doc. No. 78/4..

Listing of factors that may be used as indicators of the capability of small businesses (not necessarily high technology businesses) to perform R&D and to participate in government R. & D. contracting.

Gold, Bela. *Improving Industrial Productivity and Technological Capabilities: Needs, Problems and Suggested Policies*. Prepared for the National Center for Productivity and the Quality of Life, Washington, D.C. Research Program in Industrial Economics, Case Western Reserve University, Cleveland, Ohio, July 20, 1978.

Discussion of economic and practical aspects of industrial productivity.

Gold, C. Henry, Moore, A. M., Dodd, Bill, West, Susan G. *Technology Utilization in a Non-Urban Region: Further Impact and Technique of the Technology Use Studies Center*. Final Report, NASW–2881. Technology Use Studies Center, Southeastern Oklahoma State University, Durant, Okla., December 1976.

Applications of NASA technology in non-manufacturing areas.

Haggerty, James J. *Spin-off 1978*. National Aeronautics and Space Administration, Washington, D.C., January 1978.

Shows numerous applications of NASA technology in consumer products and services. For example, the Silverdome, fire-fighting devices, medical equipment, solar energy collectors, and electric cars.

Hahn, Walter A., Doscher, Susan L. Summary Chapter in *Industrial Technology Transfer*, Marvin J. Cetron and Harold F. Davidson (editors), Leyden, the Netherlands: Noordhoff, 1977, pp. 431–469.

Summary of the chapters on technology transfer at the NATO International Conference on Technology Transfer.

Hall, Robret W., and Vollman, Thomas E. "Planning Your Material Requirements." *Harvard Business Review*, September-October, 1978, pp. 105–112.

Materials aspects of planning and productivity.

Hersey, Irwin. "The Spin-Off from Space." *Engineering Opportunities*, February 1968, pp. 22–35.

Discussion of the use of NASA technology in other applications, with much discussion of industrial applications. Some examples are shown. Discusses the NASA Regional Dissemination Centers and how industry appears to be beginning to avail itself of this source of R. & D.

Holtz, James N. *The Technology Utilization Process: An Overview*. Division of Research, Graduate School of Business Administration, University of California at Los Angeles, November 19.

Discussion of the technology utilization process with particular emphasis on the use of space and defense research by small businesses. The report concentrates on the financial aspects of development of any new product which was a spin-off from Federal research and is concerned with the difficulty of funding for a small company or entrepreneur.

Hughes Aircraft Co. *R. & D. Productivity*, 2nd edition, 1978, Culver City, California.

A broad survey of technological contributions to productivity in R. & D.

Illinois Institute of Technology Research Center. *Solving Manufacturing Problems Through Aerospace Technology*. NASA/IITRI Manufacturing Applications Team 1977 Yearly Report, IIT Research Institute, Chicago, Illinois, 1977.

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[5] POMRAD document number.

Applications of NASA technology to manufacturing problems, with many examples.
Iron Age. "NASA/AEC Spinoff: Answers Waiting for Question." *Iron Age*, January 28, 1974, pp. 33–37.
Describes the AEC Technology Utilization Program. Gives some case studies from NASA and AEC transfer to industry.
———"Metalworking's Future Manufacturing Systems." *Iron Age*, August 28, 1978.
A major survey of future manufacturing systems, including many instances of imbedded technology and future equipment that embodies it.
Jedlicka, Allen D., and Rubenstein, A. H. "Some Observations on the Strategies and Organization of Applied Research Institutes in Developing Countries." Department of Organization Behavior, School of Businesss Administration, University of Northern Iowa, Cedar Falls, and Department of Industrial Engineering and Management Sciences, Northwestern University, Evanston, Ill., November 1974. Document No. 75/7.
Johnson, F. Douglas, Gatseas, Panayes, Miller, Emily, Gundersen, Nancy. *NASA Tech Brief Program: A Cost Benefit Evaluation.* Transfer Research and Impact Studies Project, Industrial Economic Division, University of Denver Research Institute, Colorado Seminary, May 1977.
Shows that the benefit-to-cost ratio for the Tech Brief/Technology Support Package program is 10:1. See page ix. Chart on p. 12 (Table I–4) shows various U.S. agency budgets for technology transfer.
Jolly, J. A., Creighton, J. W., (editors). *Technology Trnasfer in Research and Development.* Naval Postgraduate School, Monterey, California, 1975.
Figure 8–1, Predictive Model of Technology Transfer, p. 84. Figure 1–12, Activities Applied to the Basic Linker Model, p. 13.
Keating, Bern. *Henry Ford, Move Over! American Way*, November 1978, pp. 23–26.
Brief popular account of the contribution of Sam Colt to mass production.
Kottenstette, James P., Freeman, James E. *PATT: Project for the Analysis of Technology Transfer.* Industrial Economics Division, Denver Research Institute, University of Denver, Denver, Colorado, July 1972.
This final report is more descriptive of the methodology used in the project than informative on technology transfer. Of special interest are Appendix A: Nondestructive Testing Fact Sheet; Appendix B: Cryognics Fact Sheet.
Lesher, Richard L., Howick, George J. *Assessing Technology Transfer.* Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration, 1966.
A book on the process of technology transfer (TT) from government sponsored R. & D. to the private sector. On how to do TT—pp. 30–31; difficulties of TT—pp. 40–41; programs for TT—pp. 55–73; steps in TT process—pp. 88–89; examples of NASA/AEC TT—pp. 103–5.
National Academy of Sciences. *Research Management and Technical Entrepreneurship: A U.S. Role in Improving Skills in Developing Countries.* Washington, D.C., 1973.
Transfer of skills to Less Developed Countries (LDCs).
National Aeronautics and Space Administration. *Useful Technology from Space Research.* Technology Utilization Program, Washington, D.C., 1968.
Gives some examples of NASA's R. & D. applied to other applications including some industrial uses. Shows a map of Regional Centers for NASA data.
——— *Summary Descriptive Information on a Random Selection of Transfer Examples.* Technology Utilization Division, Office of Technology Utilization, Washington, D.C., March 1969.
Contains about 100 case studies of the technology transfer of R. & D. findings by NASA used in medical and industrial applications.
——— *Applications of Aerospace Technology in Industry: A Technology Transfer Profile.* Washington, D.C., 1971–72.
Several volumes containing case studies on the following areas of Technology transfer; patient monitoring; cryogenics; non-destructive testing; welding; visual display systems; fire safety; food technology; and plastics.
——— *Index to NASA Tech Briefs.* NASA SP–5021 (14). Washington, D.C., February 1974.
An index with abstracts of NASA Tech Briefs. Tech Briefs are short announcements of new technology derived from the R. & D. activities of NASA

or the Atomic Energy Commission. These briefs emphasize information considered likely to be transferable across industrial, regional or disciplinary lines and are issued to encourage commercial application.

——— *Technology Utilization: Fabrication Technology, A Compilation.* NASA SP–5978(02). Washington, D.C., September 1974.

Gives case studies of developments in metal fabrication, cutting and finishing made under NASA contracts. Object of the booklet is to make the information available to the private sector.

——— *Technology Utilization Program Report.* Technology Utilization Office, Washington, D.C., 1974.

A discussion of natural diffusion (pages iv–v). This report contains numerous technology transfer case studies in two broad categories: public sector projects; and biomedical sector projects, with further breakdown within these two categories. Examples of the TT case studies are: recycling valuable nonferrous metals from discarded autos, lead paint detectors, improved brake linings, and nickel-zinc batteries.

——— *Technology Utilization—Mechanical Devices, A Compilation.* SP–5976 (05). Washington, D.C., January 1976.

Some mechanical devices developed by persons under NASA contracts. Object of these tech briefs is to inform the private sector of available spin-offs from NASA research.

National Research Council, Assembly of Engineering. "Annual Program Plan FY 1979." Committee on Computer Aided Manufacturing, Washington, D.C., June, 1978.

Description of the Air Force sponsored program on computer aided manufacturing.

National Science Foundation. *Intergovernmental Science and Public Technology.* Program Report, Vol. 2, No. 6, September 1978. Presented by the Directorate for Applied Science and Research Applications, Division of Intergovernmental Science and Public Technology and prepared by the Office of Planning and Resources Management, Division of Strategic Planning and Analysis.

Summary of a number of National Science Foundation-sponsored experimental incentives and cooperative R. & D. programs.

——— *Federal Technology Transfer—An Analysis of Current Program Characteristics and Practices.* A report prepared for the Committee on Domestic Technology Transfer, Federal Council for Science and Technology. Office of National R&D Assessment, Washington, December 1975.

Table 1, p. 2, factors likely to affect the success of technology transfer, research utilization programs. VI, Summary, pp. 21–24. A summary of factors likely to affect success of TT/RU programs.

Office of Technology Assessment, Congress of the United States. *Government Involvement in the Innovation Process.* A contractor's report to the Office of Technology Assessment. Washington, D.C., August 1978.

Broad discussion of incentives, barriers, and other effects of government on the innovation process.

Olson, Walter T. *Making Aerospace Technology Work for the Automotive Industry—Introduction.* Technical paper presented at the 1978 Congress and Exposition of the Society of Automotive Engineers, Detroit, Michigan, February 27–March 3, 1978. NASA Technical Memorandum TM–73870.

Application of NASA-supported technology in the automotive industry.

Palmer, Archie M. *Administration and Utilization of Government-Owned Patent Property.* National Aeronautics and Space Administration, Washington, D.C., December 23, 1960.

On p. 24 there are some data on the low commercial utilization of government patents, although these are somewhat dated. The report goes on to speculate over the reasons for the low usage rate.

Pavitt and Walker, "Government Policies Towards Industrial Innovation: A Review." *Research Policy*, Vol. 5, No. 1, January 1976.

A multi-country study of incentives to innovation based at University of Sussex, England.

Rubenstein, A. H. "Problems of Financing and Managing New Research-Based Enterprises in New England." A study done for the Research Department of the Federal Reserve Bank of Boston, April 1958. Doc. No. 58/1.

A study of the growth and problems of new high technology starts ups.

Rubenstein, A. H., Douds, Charles F., Geschka, Horst, Kawase, Takeshi, Miller, John P., St. Paul, Raymond, and Watkins, David. "Management Perceptions of Government Incentives to Technological Innovation in England, France, West Germany, and Japan." *Research Policy*, Vol. 6, No. 4, 1977, pp. 324–357 Doc. No. 75/95.

A multi-country study of the reactions of industrial managers to government incentives to innovation, coordinated by POMRAD at Northwestern University.

Rubenstein, A. H., "Designing Organizations for Integrating Technology Exchange Transactions (TETs) in Developing Countries." Prepared for 2nd Caribbean Seminar on Science and Technology Planning, Port of Spain, Trinidad, January 1976. Doc. No. 75/109.

Discussion of the design of networks for the transfer of technology, technical assistance and technical information in Latin America.

——— "Some Observations on the Effectiveness of Federal Civilian-Oriented R&D Programs (FC/R&D)." *Policy Studies Journal*, vol. 5, No. 2, Winter 1976. Also in *Priorities and Efficiency in Federal Research and Development*, Congress of the U.S., Washington, D.C. 1976, pp. 46–64. Doc. No. 76/1.

A paper prepared for the Joint Economic Committee on incentives/barriers to innovation.

——— "Some Issues on International Technology Transfers in the Context of National Security." Prepared for National Security Affairs Conference, July 12–14, 1976, Washington, D.C., Doc. No. 76/43.

A paper prepared for the National Security Conference dealing with international technology transfer and the specific problems of technical know-how.

——— "Progress Report on Caribbean Combined Task Force on Technology Exchange and Funding Mechanisms." Report prepared for the Organization of American States, July 1976. Doc. No. 76/50.

Report on attempts to implement the concept of a Technology Exchange Transaction (TET) network in the Caribbean.

——— (with John E. Ettlie). "Innovation Among Suppliers to Automobile Industry: An Exploratory Study of Barriers and Facilitators." To be published in *R&D Management*, 1979. Doc. No. 77/22.

Report of a study of 32 innovations in the automotive industry, including factors serving as barriers and facilitators to innovation.

Rubenstein, A. H., Bergman, M., Geisler, E., and Thompson, C. W. N., "Final Report on a Preliminary Study of Indicators for Small Business R&D Capabilities." Prepared for the National Science Foundation, October 1977. Doc. No. 77/63.

An exploratory study of the capabilities of small business to conduct R&D/Innovation.

Rubenstein, A. H., Geisler, E., "Potential Indicators and Measures of Downstream Outputs of the R&D/Innovation Process in Several Sectors of Science and Technology." Prepared for the American Association for the Advancement of Science meeting, Houston, January 1979. Doc. No. 78/54.

A summary of a number of studies done by POMRAD related to indicators for the R&D/Innovation process, including work in the environment, small business, energy, transportation, materials, industrial products, agriculture, and public heath.

——— "Preliminary Unsolicited Research Study Proposal on Source Selection, Monitoring, and Contractor Past Performance." A proposal submitted to the Air Force. Department of Industrial Engineering and Management Sciences, Northwestern University, August 1978. Doc. No. 78/58.

A proposed study of the factors describing past performance which may be relevant to source selection and monitoring contracts.

Saunders, Neal T. *Overview of NASA/OAST Efforts Related to Manufacturing Technology*. Presented at the MTAG–76 DOD Tri-service Conference on Manufacturing Technology, Arlington, Texas, November 8–11, 1976. NASA Technical Memorandum TM X–73583.

Contributions of NASA technology specifically to the manufacturing processes.

Schmidt, Robert D. "Technology Transfer: More Rope or Which Rope?" *Government Executive*, December 1978, pp. 18–21.

Discussion of several aspects of international technology transfer and the situation of technological dependence.

Schmied, Helwig. "A Study of Economic Utility Resulting from CERN Contracts." *IEEE Transactions on Engineering Management*, Vol. EM–24, No. 4, November 1977.

Spin-offs from CERN to contractor capabilities.

Schnee, Jerome E. *Government Programs and the Growth of High-Technology Industries*. Graduate School of Business Administration, Rutgers University, New Bruswick, N.J., February 1976.

Contributions of DOD and NASA programs to the growth of high technology companies in electronics, aerospace, computers, and related industries.

Science. Technology Creep and the Arms Race: ICBM Problem a Sleeper. Science, Vol. 201, September 22, 1978, pp. 1102–1105.

One article in a series on the incremental, non-obvious advance of military and military-related technology which cumulatively leads to step advances.

Stanford Research Institute. *Technology Assessment of Telecommunications/Transportation Interactions, Vol. III, Contributions of Telecommunications to Improved Transportation System Efficiency*. Prepared for National Science Foundation. Menlo Park, California, May 1977. NTIS PB–272 696.

Contributions of telecommunication to efficiency, productivity, and economics of various transportation sub-sectors.

Technlogy Application Center. *TAC News*, October 1978. A Division of the Institute for Applied Research Services, The University of New Mexico, Albuquerque, N.M.

Description of services in one of NASA's Technology Application Centers.

Tesar, Delbert. "Mission-Oriented Research for Light Machinery." *Science*, Vol. 201, September 8, 1978, pp. 880–887.

The U.S. lag in development and use of intelligent machines.

Towill, Denis R. "An Industrial Dynamics Model for Start-Up Management." *IEEE Transactions on Engineering Management*, Vol. EM–20, No. 2, May 1973 pp. 44–51.

Mathematical treatment of start-up models.

U.S. Air Force. *ICAM Third Annual Industry Briefing*. Cincinnati, Ohio, 13–15 June 1978.

Detailed description of the Air Force's Manufacturing Technology Program.

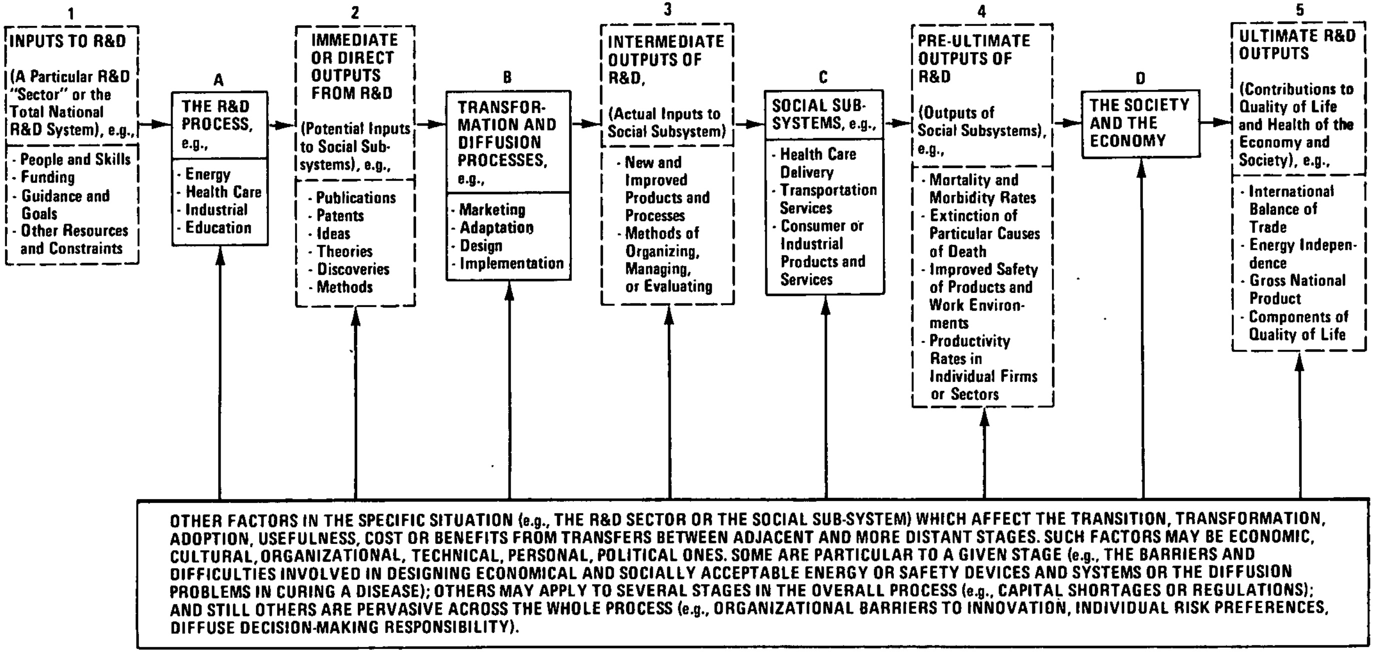
Watkins, David, Rubenstein, A. H., St.-Paul, Raymond, Peters-Koehler, Barbara, Douds, Charles F. "Innovation Incentive Programmes in Three West European Nations: France, West Germany, and the United Kingdom." *Technological Innovation, The Experimental R&D Incentives Program*, Denver Research Institute. Boulder, Colorado: Westview Press, June 1977, pp. 265–289. Doc. No. 76/9.

Descriptions of incentives for industrial innovation provided by three European countries.

Watson, Donald S., Holman, Mary A. *An Evaluation of the Patent Policies of the National Aeronautics and Space Administration*. Department of Economics, The George Washington University, Washington, D.C. 1966.

Table 4–3 on p. 72 shows sources of information about NASA inventions. Some specific case studies, pp. 80–86.

FIGURE 1: A PRELIMINARY CONCEPTUAL MODEL OF THE LINKAGES BETWEEN THE R&D PROCESS AND SOCIAL SYSTEMS



Source: A. H. Rubenstein, POMRAD, Northwestern University, 1975.

FIGURE 2.—Some illustrative indicators of imbedded technology in small business.

Factor:	
(1) Marketing (of R. & D.) sophistication	(*a*) Familiarity with government bid procedures.
	(*b*) Bid strategy.
	(*c*) Information system for learning about opportunities (e.g. requests for proposals).
(2) Technical information	(*a*) Technical journals and reference sources subscribed to.
	(*b*) Procedure and facilities for searching for technical information.
(3) R. & D. facilities and equipment	(*a*) Expenditures and inventory of equipment and instruments (E. & I.).
	(*b*) Replacement and up-dating of E. & I.
	(*c*) Ability to maintain and adapt E. & I.
(4) Track record in performance	(*a*) On time and on cost delivery record.
	(*b*) Returns, allowances, disputes on specifications and quality of delivered items.

Source: Rubenstein, Geisler and Thompson, 1977; POMRAD Doc. No. 77/63.

FIGURE 3.—Potential application of indicators for IT to procurement/acquisition of high technology items.

A. APPLICATION TO SOURCE SELECTION

Such indicators should be useful to procurement and contracting specialists in procurement offices involved in the source selection process in the following ways:

Suggesting new indicators of past performances as guides to likely future performance.

Providing measures to use for those indicators which are considered appropriate.

Providing a systematic framework within which past performance can be evaluated and weighed in with other factors.

Reconciling formal or intended methods of weighing past performance with actual methods used, especially the wide variance among source selection groups and at different times and places and relating these, in turn, with procurement regulations.

Where decisionmakers in the source selection procedure are relatively satisfied with their current indicators of past performance and the weights assigned to them, providing an opportunity to re-examine their current practice and, perhaps, augment the indicators they use.

Where there is general dissatisfaction about the current methods of using past performance or where they are hardly used at all, providing a basis for introducing such factors. The use/non-use of past performance in source selection varies widely among Federal agencies and among units within specific agencies.

B. APPLICATION TO CONTRACT MONITORING

The indicators should be useful to program monitors and technical monitors in system program offices in the following ways:

As a supplement to existing monitoring systems that focus on cost, time, and milestones.

Where certain weak points, hot spots or potential flaws have been identified in the source selection process or in investigations of past performances.

To focus attention on key aspects of contractor present and likely future performances through "exception principle" management or monitoring.

Where current monitoring systems are inadequate, to substitute an improved one.

Providing inputs to the next cycle of contracting or monitoring for follow on or new contracts. In this way, monitoring can provide its own "past performance" data for future source selection decisions.

To provide realistic guidance as to what can be expected from the contractor, within the formal limits of contract terms.

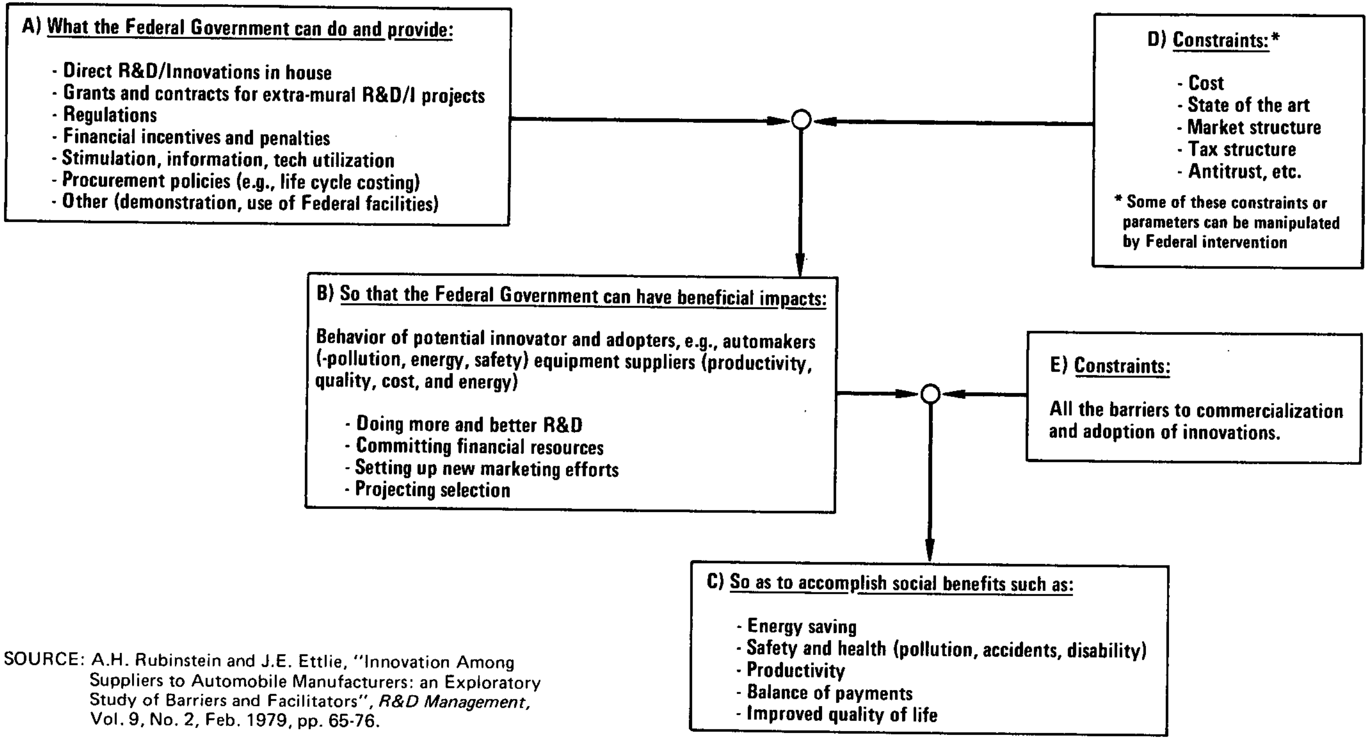
Source: International Applied Science and Technology Associates, Inc. (IASTA) 1978, Doc. 78/58.

FIGURE 4.—Some suggested Government actions to enhance the U.S. position with respect to imbedded technology (IT).

Share the cost of training of technicians and other IT specialists.
Provide tax credits for labor savings on IT investments.
Increase sharing of IT capabilities by Federal labs.
Ease licensing and waiver of IT's covered by government-owned patents.
Increase access to Federal laboratories for testing of products and materials by industry.
Stimulate action on technology transfer by Federal agencies which give primarily lip service to it (despite policy directives to participate).
Include development of IT capabilities and products explicitly as part of federally financed or federally performed R. & D.
Subsidize trade magazines which specialize in IT, in addition to professional journals which specialize in scientific and technical information (STI).
Expand the technology transfer agent programs that were tried by various agencies (e.g., NSF, NASA, Department of Commerce) and design them so that they will be more self-sustaining and more effective.
Count IT spin off as part of the social and economic benefits explicitly when evaluating cost-effectiveness of a government-sponsored R. & D. program.
Identify and target needs for IT in different fields.
Use government influence (through regulations, procurement, tax laws, direct support) to encourage investment in IT by industry.
Provide support for use of retired executives to transfer IT skills and knowledge and to provide formal training.
Conduct or support technical audits of IT in individual companies and industries on a confidential basis.
Provide incentives to larger firms to assist small firms (including some of their supplier firms) in developing independent IT capabilities.
Support research and experimentation on IT.
Direct more attention to the IT aspect of the R. & D. Innovation process, in addition to the current heavy focus on the R. & D. aspects.
Consider IT skills when establishing immigration preferences.
Consider IT skills when considering export and technology transfer regulations and individual export contracts.

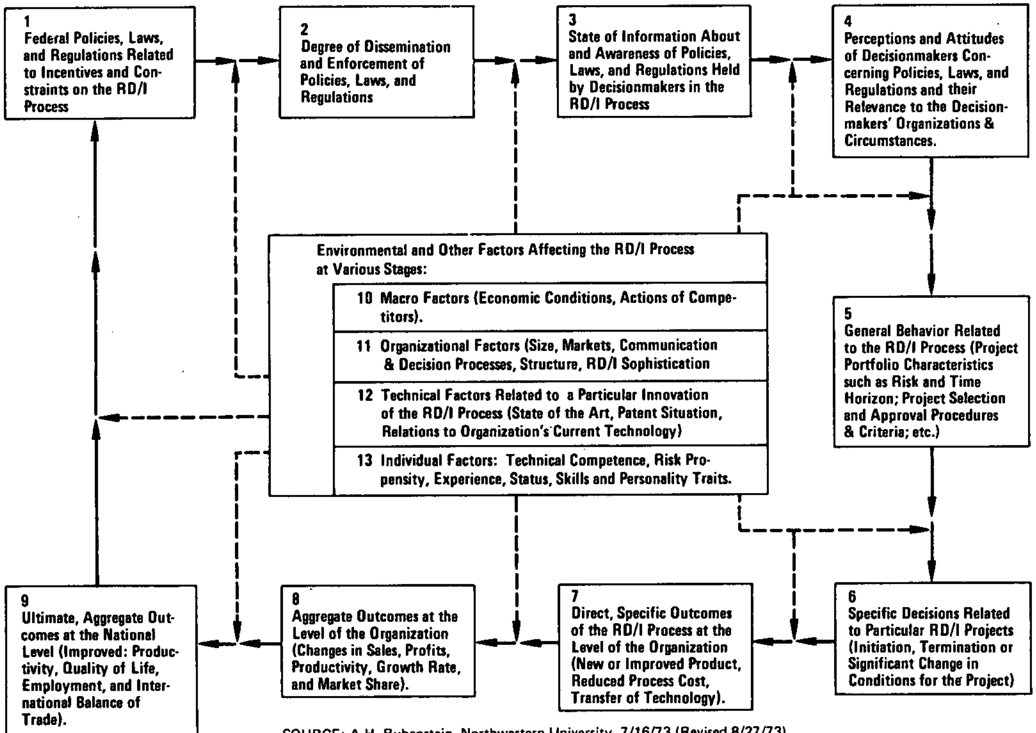
Source: Studies and ideas from members of the research-on-research community (students of the R. & D./Innovation process), including the Northwestern group, plus staff members of the National Science Foundation, NASA, Department of Commerce, practitioners of the art of R&D management in the Industrial Research Institute and outside it, and members of the various advisory subcommittees working on the two current major studies of innovation. (Domestic Policy Review and Joint Economic Committee of Congress).

FIGURE 5: AN ABBREVIATED CONCEPTUAL MODEL OF THE POTENTIAL ROLE OF FEDERAL AGENCIES IN INFLUENCING THE R&D/INNOVATION



SOURCE: A.H. Rubinstein and J.E. Ettlie, "Innovation Among Suppliers to Automobile Manufacturers: an Exploratory Study of Barriers and Facilitators", *R&D Management*, Vol. 9, No. 2, Feb. 1979, pp. 65-76.

FIGURE 6: A FLOW MODEL OF THE POTENTIAL EFFECTS OF FEDERAL GOVERNMENT ACTION AND OTHER FACTORS ON THE RESEARCH AND DEVELOPMENT/INNOVATION (RD/I) PROCESS



SOURCE: A.H. Rubenstein, Northwestern University, 7/16/73 (Revised 8/27/73).

Notation:

1) The "boxes" indicate states, such as:
   1 - Existing policies, laws and regulations;
   2 - Existing degree of dissemination and enforcement;
   3 - Existing Information State.

2) The solid "output" arrows indicate changes of state, such as:
   1 - New policies, laws, and regulations;
   2 - Increased enforcement and dissemination;
   3 - Changes in awareness and information.

3) The dashed arrows indicate effects of environmental and other factors on changes in state.

Comment:

There are certainly other relations in the process than those shown, including feedbacks (e.g., effects of "7" on "11" and effects of "4" on "1" and "2"). The model indicates the main direction of flow, however, allowing for particular stages to be missed or even encountered out of sequence (e.g., 6 or 7 leading to changes in 4, and 4 leading to changes in 1 and 2).

OUTLINE FOR A QUANTITATIVE TECHNOLOGY INDEX TO AID IN FORMING NATIONAL TECHNOLOGY POLICY

By George Foster, Marvin J. Cetron, and Audrey Clayton*

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A. Background

About four years ago, Rolf Piekarz of the National Science Foundation posed a question to staff members at Forecasting International, Ltd. (FI), which was tantamount to asking "What is the price of technology?" This is a little like asking the price of water; the answer depends on where you are, the cost in the Sahara being much higher than on the Amazon. In addressing this question we reasoned that the price for a specific piece of technology ought to lie somewhere between the cost of duplicating it and the economic value to the buyer, and that both cost and value are related to the purchaser's level of technical competence. We concluded that the relationship would be as shown in Figure 1.

When the level of the technology being transferred is high relative to that being practiced by the recipient, the cost of his duplicating it is very high, and the value to him is low because he cannot make use of it. At the other end of the scale the cost of duplication is low but the value is even lower because the recipient has something better. In the mid-range, however, there may be a region of positive price where the value exceeds the cost and it makes economic sense to purchase the technology. Whether the price would be advantageous to the seller is of course another matter.

Thus the cost of transferring technology is related to the recipient's technical competence. We assume that a nation's absorptive capacity is greatest (i.e., transfer is easiest) for technologies which are at a level similar to those which it already practices (although this is not

*Forecasting International, Ltd., 1001 North Highland St., Arlington, Va. 22210.

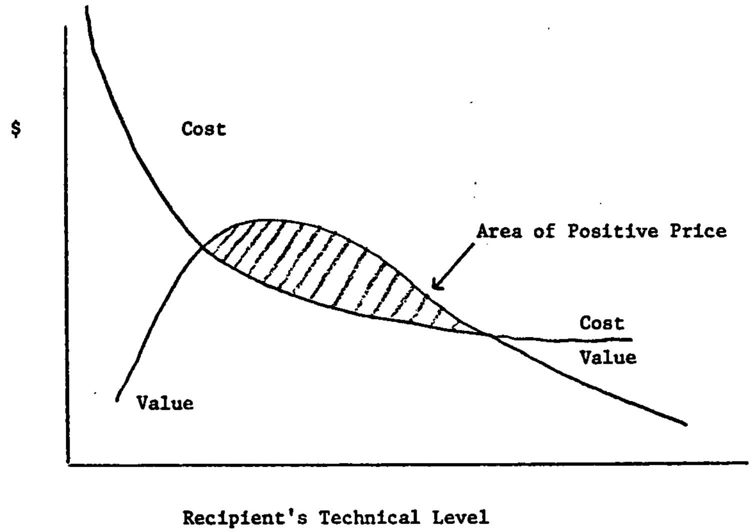

FIGURE 1. Cost/value relationship for specific item of technology

the only factor to be considered). This is an intuitively reasonable assumption, and there is abundant anecdotal evidence which can be interpreted as offering support.[1]

We can, of course, not make any claim for originality here. For example, Professor Roberts used a somewhat similar model in discussing the value of research.[2] These insights now lie within the range of "what everybody knows." Yet the concepts are hard to use in any practical way. Just what do we mean by level of technical competence or the level of an item of technology? What is an item of technology? Indeed, what do we mean by technology? In studying technology transfer, one becomes aware that there is no established quantitative index which can be applied to assess the effect or extent of whatever components are involved in the transfer.

Therefore, the Forecasting International study team, sponsored by the National Science Foundation, set out to devise an index which measures technology, or more precisely, may be used to provide a rank ordering of disparate technologies. The object of this endeavor was to be able to say something reasonably precise about the facility with which technology is transferred between nations, insofar as this is affected by the nature of the technology being transferred. That is, we dealt at this stage only with the technological component of a process dependent on an entire nontechnological infrastructure which may also affect absorptive capability in the transfer function. The problem was, then, to devise an index which ranked both the technology being transferred and that being practiced in the host country.

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[1] See far example, Baranson, Jack, Industrial Technologies for Developing Economies (New York, N.Y.: Frederick A. Praeger, 1969); also Hall, G. R. and R. E. Johnson, "Transfers of U.S. Aerospace Technology to Japan," in Raymond Vernon (ed.) The Technology Factor in International Trade (New York, N.Y.: Columbia University Press, 1970).

[2] Roberts, Private Communication, 1969.

B. Index Definition

We argue that such a measure should consider observable aspects of technology and eschew such quantities as knowledge, which are not directly observable but must be deduced from observations of technical practices; and others, for example productivity, which are almost impossible to define operationally. We wished also to avoid surrogates such as research expenditures which are frequently employed to compare one industry with another. All such surrogates suffer some deficiencies: research expenditure, for example, is an input to technology, and its correlation with any actual performance tends to be unclear and at times apparently random. The costs of research differ greatly among countries and industries, which further complicates their use as a measuring function. Many industries consume research results produced by others, and also large areas of technology are not directly fertilized by research.

In a summary publication [3] based upon this study, we defined technology as a set of integrated activities leading to the production and distribution of physical goods. The index there derived, however, was restricted to characteristics of the product itself and the manufacturing process which produced it. We have subsequently modified our index slightly to include some of the technology-related aspects of distribution, since distribution is a function of the technology and is too important to be left unconsidered. As before, we have restricted consideration to manufactured goods.

In developing a technology index, our task is to devise a set of rules for selecting technology-related phenomena to be observed; a means of scaling the observations; and an algorithm for combining the results to yield an index number characteristic of that technology. We require that:

1. The index number locates a given technology in a rank-ordering of many technologies;
2. The phenomena to be observed should encompass elements in the practice of technology and also of the transfer process; and
3. Different observers applying this algorithm should arrive at a similar index number for a given technology.

Once such an index is available, it could be used to rank all technologies and would, in fact, serve to define the level of technology operationally.

Since there is no established definition of technological level or any scheme for computing it other than an index such as we propose, we are confronted with a dilemma. In order to validate the measurement system which we derive, it is logically necessary to have some prior ranking of technologies which does not itself depend on the index. This is resolved by using the intuitive judgment of informed observers.

Psychophysicists have shown that different sets of observers can arrive at comparable rankings for quite complicated perceptions—national power, seriousness of crimes and prestige of professions, for instance.[4] Thus, it is logical to assume that agreement between the

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[3] Foster, George, and Norman Nisenoff, "Development and Implications of a Technique for Quantifying Technology," in Cetron, M. J., and H. F. Davidson (eds.) Industrial Technology Transfer (Leyden, The Netherlands: Noordhof International Publishing, 1977).

[4] Stevens, S. S., Psychophysics (New York, New York: John Wiley & Sons, 1975).

rank-ordering of technologies by independent experts (provided by the index we shall define) confers some measure of validity upon our methodology and its results.

Our approach is based upon Professor Vernon's observation [5] that as a product matures, the technical frontier shifts from the characteristics of the product to those of the manufacturing process. In the early stages of development, neither producer nor customer is entirely sure which properties are most useful: designs tend to change rapidly, and the customer is more concerned with performance differences among alternative designs than with cost differences. However, as the product matures, designs are standardized and cost becomes an increasingly important consideration: producers introduce cost-cutting production procedures. Frequently, this involves increasing capital investment and reducing flexibility, but the market is by now well-defined as to size and product requirements, so that the risk is acceptable. Competitors enter the field, perhaps using different processes, but eventually production methods become standardized also. When all producers make approximately the same product in basically similar fashion, the technology is stabilized. Vernon's observation suggests that any technology index must consider both product and process characteristics.

Product and production system are somehow related to each other. Our view as to the nature of the relationship between them is derived from a concept developed by Joan Woodward and her associates.[6] They studied the influence of production technology upon management structure, and produced a nine-point scale of production measurement, ranging from unit or small batch production at one extreme to continuous processing at the other. It was pointed out that this scale is one of increasing technical complexity.

To a surprising degree, appropriate production method was found to be independent of the specific product. For example, the production of custom-made suits has more in common with other custom production than it has with mass production of closing. The Woodward group distinguished production of integral products (those sold by the piece), from production of dimensional products which are sold by weight, volume, area or other physical dimension, because the two kinds of production present different management problems. Industries concerned with the manufacture of dimensional products—sometimes called the process industries—are particularly susceptible to the use of highly automated continuous-flow processes.

The Vernon and Woodward insights suggest many possible factors which might be considered as phenomena contributing to the construction of our proposed index. In order to develop from these an index yielding intuitively satisfactory results, we selected a small number of products that were familiar to at least two FI staff members through their having worked in the industry or having studied the product and production process. Staff were then asked to rank-order these technologies. For each algorithm empirically constructed, employing a subset of the candidate influencing factors, the resulting in-

[5] Vernon, Raymond, "Sovereignty at Bay: The Multinational Spread of U.S. Enterprises" (New York, N.Y.: Basic Books, Inc., 1971).

[6] Woodward, Joan, "Industrial Organization: Theory and Practice" (Oxford, England. Oxford University Press, 1965).

dices were compared with this intuitive ordering. We make the assumption (to be verified later) that these factors indicate activities which must be performed in a new location when the technology is transferred. They are system-specific in the sense in which Hall & Johnson use that term.[7]

Our technology index is defined as the product of three parameters: Technology of the product, process technology, and technology of distribution. Each of these is in turn the product of a set of descriptors (defined below) which indicate the technical intensity of the parameter, of the product being considered.

Our scaling rules and computational algorithm derive from the findings of Stevens and other students of psychophysics, that perceived the intensity of a stimulus increases as some power of the stimulus. If observers are asked to use a descriptive scale such as high, medium or low to rate a stimulus, they tend to treat it as a ratio scale. It has also been found that in combining several perceptions, more appropriate results are produced by using multiplication rather than addition.

Consequently, in applying this and various other algorithms tested, the team members were asked to rate product and process elements on a four-point adjectival scale—High, Moderate, Low or Negligible—according to a set of judgmental criteria provided to them as a result of earlier "brainstorming." These ratings were converted to numerical values using a ratio scale (8, 4, 2, 1).

Once the criteria are developed, this approach is very practical since evaluators assign values rapidly without dithering over marginal differences. Efficiency was an important consideration because we calculated index numbers many times trying different sets of elements before settling on the present group. The definitions of the elements finally selected, and criteria which were employed in making the judgment, are detailed in the following paragraphs.

1. *Product Descriptors*

(1) S_d—Technical Difference Among Products of Competing Suppliers

This factor was chosen on the assumption that extent of technical difference is related to the state of maturity of the products. If the differences are large, the product technology has not yet "settled down."

Rating	Interpretation	Examples
Negligible—1 point	Competing products are fungible, differences are matters of taste or style.	Commodity chemicals; most consumer dispcsables.
Low—2	Differences among competing products are noticeable, i.e., product uniformity, but changing supplier does not require user to make significant change in methods.	Specialty plastics.
Moderate—4	Technical differences are large. Changing supplier involves a learning cost to user.	Reforming catalysts.
High—8	Unique product from each supplier.	

[7] Hall, G. R., and R. E. Johnson, op. cit. in footnote 1.

(2) T_s—Service Technological Content

This factor is intended to measure the technological content of the service which accompanies the product. Service can range from the provision of simple written directions, through training of service maintenance personnel, to assistance from highly trained applications engineers. It is included here rather than under distribution under the assumption that "product plus service" constitutes a product package.

Rating	Interpretation	Examples
Negligible—1 point	Service consists of little more than written direction on package, or occurs only at time of initial contact between supplier and user.	Consumer disposables basic chemicals.
Low—2	Product service—supplier maintains stock and spare parts, offers repair service, routine trouble shooting.	Automobiles; Machine tools.
Moderate—4	Technical service—product service with laboratory or engineering support.	Specialty plastics.
High—8	Product development—supplier continues to interact with user to develop products tailored to his needs.	Custom-designed machinery—special purpose computers, construction equipment.

(3) R_c—Rate of change

This parameter is intended to indicate that rate at which a product is supplanted by improved versions or its function assumed by different product. It measures the technological intensity of the product field.

Rating	Interpretation	Example
Negligible—1 point	Product life measured in decades except for fashion and style changes.	Nails; basic chemicals.
Low—2	Product changes occur at regular intervals but are usually minor, e.g., redesigns to introduce new materials or style changes.	Automobile engines.
Moderate—4	Product changes occur at regular intervals (2–10 yr) and change involves substantial redesign.	Large computers.
High—8	Significant changes occur erratically but with an average frequency of 2 yr or less.	Hand calculators.

2. *Process Indicators*

(1) P_s—Production system

This element is taken to indicate the technological content of the method of production used.

Rating	Interpretation	Examples
Unit/small batch—1 point	Production of units to customers' requirements. Production of prototypes. Fabrication of large equipment in stages. Production of small batches to customers' orders.	Television transmitters.
Large batch—2	Production of large batches. Production of large batches on assembly lines. Intermittent production of chemicals in multipurpose plant.	Readymade clothing; machine parts; paint.
Combined—4	Process production of crystalline substances, subsequently prepared for sale by standardized production methods. Production of components in large batches subsequently processed continuously	Drugs.
Mass—8	Continuous flow production of liquids, gases, and crystalline substances. Mass production.	Petrochemicals, paper, carbboard boxes nails, screws.

(2) M_f—Material form

This factor is included to take account of the fact that it is inherently simpler to process materials in bulk form (dimensional products) than it is to process discrete units. No ranking equivalent to 8 (High) is provided because none is required for this factor. This does not of course affect subsequent comparative and combinatorial computations.

Rating	Interpretation	Examples
Fluid—1 point	Material is handled predominantly as fluid or free-flowing solid throughout production process.	Petrochemicals.
Bulk—2	Materials are handled largely as dimensional solids, or in bulk form.	Wire or film; nuts and bolts; resistors.
Integral—4	Material is handled as integral units	Automobile assembly.

(3) Q_m—Quality Maintenance

This factor is included on the assumption that expenditures for quality maintenance, as a proportion of total product cost, are a measure of the difficulty of the production task. We use the term quality maintenance rather than the more usual quality control because we wish to include such cost items as the provision of dust-free atmosphere, as well as product and material testing.

Rating	Interpretation	Examples
Negligible—1 point	Observe standardized manufacturing procedures with routine check of machine settings. Visual inspection of product. Good housekeeping procedures to avoid contamination.	Fertilizers; foodstuffs.
Low—2	As preceding but coupled with product inspection using go/no-go gages on statistical sample.	Machine parts.
Moderate—4	Continuous monitoring and adjustment of process equipment. May be coupled with "on-line" gaging of product.	Chemicals; active electronic components.
High—8	As preceding but coupled with performance testing of all products. Careful control of operating environment where necessary.	Drugs; computer circuits.

3. *Distribution Indicators*

(1) E_t—Technological Evolution

This factor is concerned with the producer's efforts to obtain technologically differentiated products. Most industrial product research is of this nature. It is assumed that technological rivalry is most intense when a technology is evolving rapidly, and when the technology is sufficiently rich and complex to offer unexploited opportunities.

The factor is included as a distribution indicator because it strongly affects a company's marketing strategy.[8]

[8] Stopford, John M. and Louis T. Wells, Jr., "Managing the Multinational Enterprise Organization of the Firm and Ownership of the Subsidiaries" (New York, New York: Basic Books, Inc., 1972).

Rating	Interpretation	Examples
Negligible—1 point	Little or no continuing effort	Basic metals; most consumer goods.
Low—2	Product improvement—periodic reformulation and redesign or continuing effort to obtain marginal quality improvement.	Office machinery; synthetic fibers.
Moderate—4	Market development—continuing effort to extend product line or increase application.	Large computers.
High—8	New technology—continuing effort to introduce new technological concepts.	Solid state electronic components.

(2) D_c—Distribution Chain

This indicator is concerned with the technology content of the distribution chain, e.g., the level of training required by those involved in selecting the product.

Rating	Interpretation	Examples
Negligible—1 point	Not applicable because product is consumed by producing firm or selection requires only basic skills such as ability to read directions.	Most consumer products.
Low—2	Somewhat specialized distribution but adequate knowledge is acquired on job or with a few weeks formal training.	Automobiles.
Moderate—4	Selection of product requires interaction between technically trained representatives (engineers or equivalent) of buyer and seller.	Industrial equipment; ethical drugs.
High—8	Selection of product involves interaction of highly trained representatives (advanced degree) of buyer and sellers (lab-to-lab selling).	Special purpose controllers.

(3) M_t—Market type

This factor is viewed as a kind of intensifier, the assumption being that distributing a technologically intensive product becomes more difficult as the market becomes larger and more complex.

Rating	Interpretation	Examples
Negligible—1 point	Internal consumption or few specialized purchasers.	Transfer machines.
Low—2	Industrial product used in variety of industries.	Polymer raw materials.
Moderate—4	Wide use among many customers	Building materials; synthetic resins.
High—8	Consumer product	Automobile.

C. Policy Applications

This section addresses, by means of three case studies, the question of how a technology index can be applied to illuminate some issues of technology policy. One such issue is identified by the term "La Dependencia," and is exemplified by consideration of the following example.

1. *Automobile Tires*

Consider Acme Rubber, a relatively small U.S. producer of tires, which found it had to establish foreign affiliates if it was to maintain a satisfactory rate of profit growth. It lacked the capital to establish wholly owned subsidiaries, as its larger competitors were doing, but even if this were not the case competitors were already entrenched in the most attractive markets. Acme approached its problem by learning to operate in South American, Asian and African countries by establishing tire companies in which it has little or no equity.

Acme offers three services to countries which want to manufacture tires domestically: Contracts to design and build a plant; management contracts; and technical agreements.

(1) *Turnkey plant.*—If Acme decides the local market can support a factory it will design the plant, purchase the equipment, train the operating staff and in general do all the many things necessary to put a local firm in business. The package includes immense amounts of detailed information on formulation operating procedures, names and locations of suppliers of materials and equipment, etc.

(2) *Management contract.*—If the local affiliate wants to retain this relationship with Acme, the U.S. firm offers to locate three top executives—to head production, marketing and finance—who will manage the local firm's business. The contact with Acme is minimal; the local managers send five-year plans which are updated annually and periodic reports on company performance. If the plans appear sound and progress is according to plan, U.S. Headquarters does little more than send congratulations. However if Headquarters spots a discrepancy—e.g., the five-year marketing plan indicates a plant expansion is necessary but the financial plan makes no provision for capital expenditures—or if performance is falling off, then Headquarters will seek to find the reason and offer assistance. This may mean sending a delegation to local government officials to convince them to allow the company to raise prices. It may also require that the U.S. firm resurvey local markets to determine if conditions have changed in some way that the local firm is not considering.

(3) *Technical agreement.*—Acme offers its affiliates assistance in solving any technical problems that they may encounter. These arise frequently because of changes in raw material, product design and the like. Making even apparently minor changes in tires frequently entails extensive testing on costly equipment which is difficult for a small plant to finance. Acme, however, can spread the cost among its own operations and those of all the affiliates who enter the technical agreement. In addition the company has had years of experience solving most of the problems an affiliate is likely to encounter, so the technical agreement is attractive to affiliates. Acme makes it more so by offering complete access to technical information on any product Acme produces excepting only those in the research and development stages.

Table 1 uses our proposed index to contrast the level of technology practiced by Acme in the U.S. with that practiced by an affiliated firm.

Acme transfers a great deal of technology under its agreements. If the host country is poorly industrialized, as most are, the pools of factory labor and of middle management are augmented appreciably. The firm has acquired not only the special skills required to build tires but also some (e.g., production scheduling) that are more widely applicable. The imports of the country are reduced by an amount approximately equal to the value added by manufacture. However the host

TABLE 1

Indicator	Rating	
	United States	Affiliate
1. Technical difference, S_d	2	2
2. Service technological content, T_s	4	2
3. Rate of change, R_c	2	2
Total product rating	16	8
4. Production system, P_s	2	2
5. Material form, M_f	2	2
6. Quality maintenance, Q_m	2	2
Total process rating	8	8
7. Technological evolution, E_t	2	1
8. Distribution chain, D_c	2	2
9. Market type, M_t	4	4
Total distribution rating	16	8
Total technology index	1,048	512

does not acquire the full technical service or product evolution capacity, and this means it does not acquire the capacity to cope with change. Without this the affiliate cannot hope to compete in world markets nor indeed to remain competitive in its home markets without protection by means of tariff barriers or restrictions on new entrants.

After the first flush of enthusiasm passes, the Government of the host country may not find the bargain so attractive. It will note the continual drain on reserves of foreign currency and may conclude it is paying dearly for "handbook technology"—not a one-time entry fee but a continuing monopoly rent. In the short range the country has no choice, and recognition of its technical dependence and lack of palatable alternatives makes for anger and bitter frustration.

To escape this dilemma the country has to develop its technical resources. The index suggests that what is needed in this instance is the acquisition of skills and capabilities in down-to-earth formulation and testing. The host country should forego basic research such as elegant programs to study the rheology of elastomers.

2. *Consumer Electronics and Automobiles*

Consider the examples of more "sophisticated" products such as automobiles and television sets, which are still not representative of what is usually termed "high technology". The United States in recent years has had a negative balance of trade in both these areas. As shown in Table 2 neither of these products has an especially high index, and technology is not an impassable barrier to foreign entrants into the market. More than that, the index implies that it will be difficult for any producer to obtain a position of technological leadership since in both cases the technology has become mature. (Note that we are still talking about technology only, not quality of management or marketing skill which also affect commercial success.)

The index is a little misleading in this instance, however, since it does not take account of the level of technology of product components

TABLE 2

Indicator	Rating	
	Automobiles	Television sets
1. Technical difference, S_d	2	2
2. Service technological content, T_s	2	2
3. Rate of change, R_c	2	2
Total product rating	8	8
4. Production system, P_s	2	2
5. Material form, M_f	4	4
6. Quality maintenance, Q_m	2	2
Total process rating	16	16
7. Technological evolution, E_t	2	2
8. Distribution chain, D_c	2	2
9. Market type, M_t	4	4
Total distribution rating	16	16
Total technology index	1,048	1,048

or the tools required to make them. Some will have a higher rating than the products themselves. This is to say that a plant to assemble automobiles and TV sets from purchased components could be established in a country having a relatively modest industrial base. Making some key components, e.g., engines and picture tubes, however, is more demanding.

The index implies that the deterioration of the U.S. trade position in automobiles and TV receivers is not indicative of inferior U.S. technology. Rather it suggests that the technology is mature and readily available to any industrialized country. Government policies which are keyed to stimulating U.S. technology are unlikely to improve the U.S. trade position in this particular market segment. U.S. producers, however, can expect to cut production costs and make product improvements through technical advances. Unfortunately since the technology is rather mature, foreign producers can copy and commercialize such developments about as rapidly as U.S. firms.

3. *National Champions: The Case of Large Computers*

Many countries envy the United States' domination of world trade in large computers and would like to establish a national champion like IBM. In this case the technology is a formidable barrier to new competitors; a new producer has to master an intricate product technology, a stringent production technology and a technologically intensive distribution system. In addition the field is moving so fast that technological leadership is a real advantage. This is in distinct contrast to the previous examples.

The index rating for large computers (see Table 3) implies that a nation which wants to develop a national champion to compete with IBM needs to develop a broad technology-based strategy which includes product design, manufacturing and distribution. No single development will suffice.

TABLE 3

Indicator	Rating, large computers
1. Technical difference, S_d	8
2. Service technological content, T_s	4
3. Rate of change	4
Total product rating	128
4. Production system, P_s	1
5. Material form, M_f	4
6. Quality maintenance, Q_m	8
Total process rating	32
7. Technological evolution, E_t	4
8. Distribution chain, D_o	4
9. Market type, M_t	2
Total distribution rating	32
Total technology index	131,072

D. Conclusions

1. *Utility of This Concept*

A technology index such as we have discussed in this paper can become an important tool for those concerned with technology policy.

The index has two virtues:

In providing an operational definition of technology, it offers analysts and policymakers a baseline or reference point for their discussions. This should help to minimize the confusion inherent in such nebulous terms as high technology.

It distinguishes and points up the differences among technologies. Thus it facilitates tailoring policies and strategies to the requirements of specific situations, as demonstrated by the case studies of the previous section.

However, recognition of the utility of such a concept both for those who formulate policy and for those concerned with the best methods of implementation, is only the first step. All that we have presented here is a "broadboard" model index rather than a finished mechanism to provide inputs for decisionmaking. Considerable refinement is needed.

2. *Limitations of Research to Date*

The index as here defined is supported by a meager data base. It would be desirable to increase this substantially by accumulating detailed information on industrial practices here and abroad to discover if they fit comfortably into this schema. Indexing methods have procrustean tendencies and it is well to know the limits of whatever schema is being used. Whether something "fits comfortably" into a system is, obviously, a matter of subjective judgment and at present we see no way to avoid subjectivity in estimating technical level. It would be of value, however, to incorporate judgments of people who are expert in the particular technologies being considered. There are various means of achieving this, but the end result is an agreed-upon ranking of technologies and technology elements. With this kind of data it would be possible to:

Test the indexing schema for completeness and consistency. How much does it explain? What are the anomalies?

Weigh the index elements. For example, which is the more important descriptor, technological evolution or distribution chain?

Devise a method of including the technology ratings of components in the rating of the final product.

A significant limitation was also imposed, at an early stage of the research, in the decision to concentrate on characteristics of the technology (see Section B of this paper). Clearly there are other factors, including societal differences [9] and perceived needs/desires of both donor and recipient institutions or nations, which will play a dominant role in determining the "absorptive factor" in specific instances of technology transfer. The influence on motivation and leadership is well illustrated in the consequences of the decision by Japan in 1867 to adopt a deliberate policy of absorbing western technology. It may well be, however, that unless and until equivalent indicators can be identified in nontechnological areas, the only means of determining in-place capability to absorb new technology will be a detailed examination of what has already been accomplished in this regard.

E. Summary

Technology is of ever-increasing significance in our development of national policy. The technological status of the U.S. and its implications for our national welfare are receiving attention at all levels of government and industry. This is a highly complex issue, and the concern of governmental policymakers is currently manifested by the examination of various aspects of the problem by House and Senate Subcommittees, the Congressional Office of Technology Assessment, the National Security Council, the Office of Science and Technology Policy, the International Trade Commission, the National Science Foundation, and the Departments of State, Defense, Treasury, Commerce and Labor.

In testimony [10] before the Stevenson Committee (Joint Hearings by the Senate Subcommittees on Science, Technology and Space, and on International Finance) Dr. Bruno Weinschel, IEEE Vice President, emphasized that two of the primary characteristics of technology are that it grows and it moves. It seems inevitable that, in a more closely intertwined world, technology transfer will be more frequent, more sought-after, more costly—and more controversial.[11]

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[9] For instance, in the example reported in the previously cited Hall and Johnson study, the point was made that employment by a large Japanese firm implies a lifetime commitment which results in a higher number of labor hours per unit of output than are technically required, or typically observed, in the U.S. Another example of differences of national outlook arose in that study over quality control. To give their decisions the ring of authority, and to save face among workers whom they implicitly "criticized," Japanese inspectors had to be given a higher rank in the corporate organization than their U.S. counterparts enjoyed.

[10] Statement by Dr. Bruno O. Weinschel on behalf of The Task Force on U.S. Innovation in Electro-Technology of the U.S. Activities Board, Institute of Electrical and Electronics Engineers, Inc., concerning U.S. High Technology: Impacts on U.S. Policy Affecting World Markets, May 16, 1978. Prepared under subcontract by Forecasting International.

[11] Kleiman, Herbert S., and William M. Jamieson, "Two Faces of International Technology Transfer," A Batelle Special Report. Batelle Today, No. 10, November 1978.

Development of adequate criteria for assessment of the implications of such transfer, and the efficacy and/or desirability of measures of control, can occur only following a structured and focused effort to understand the nature of technology and its characteristics, and the relative importance of these characteristics in contemplated instances of technology transfer. An index of the nature discussed in this paper is of major significance to such an effort.

THE ROLE OF SMALL-SCALE TECHNOLOGY IN INNOVATION

By Wendy H. Schacht*

CONTENTS

Abstract

Technology has, in part, shaped the American lifestyle. Innovation has become basically "technology driven"—new products and processes are developed because the know-how and expertise are available rather than in response to a defined need. These sophisticated, standard technologies have alleviated certain problems and created others. As economic, social, environmental, and cultural standards have changed, new and different demands are being made by the public. In recognition of this situation, innovation in small-scale technology is becoming a part of the U.S. scientific and technological endeavor. Small-scale technologies are generally labor-intensive, use local materials, are easy to maintain and repair, require minimal capital investment to acquire and operate, and utilize renewable or abundant resources. These technologies also tend to foster self-reliance and decentralized decisionmaking. They offer an alternative mechanism to reach an objective or meet a demand. In pursuit of economic growth a balanced approach to both standard and small-scale innovation is necessary. Innovation in small-scale technology offers a different perspective on the process of invention but it does not preclude nor deny the importance of traditional practices. It is a way of reacting to the increased demand for understandable technology, for technology over which the individual has control, and for technology which reflects individual needs and the requirements of the local environment. By expanding the type of technologies available through innovation, the store of technologies from which to select and meet the demands of a changing society can be increased.

Introduction

Innovation is a vital component of American economic growth and prosperity. As such, it is a topic which has received considerable atten-

*This paper was prepared by Wendy H. Schacht of the Congressional Research Service and does not necessarily represent the views of the CRS.

tion both in Government policy and intellectual research. Up to the present, the emphasis has been on the development of increasingly sophisticated, complex technologies; but new ideas are emerging which are gradually beginning to take shape and be acted upon. These ideas embrace the concept that alternatives to standard technologies must be developed; different products and processes which can address some of the problems conventional technologies have either created or failed to alleviate.

As our environment and values change, as our lifestyles are modified, and as new demands are developed, the concept of alternative, small-scale technology is beginning to enter into the collective consciousness of the population. Innovation for this type of technology has been slow to gain recognition but it is nonetheless a force which is growing, solidifying, and gaining acceptance throughout the United States. This paper attempts to convey why this is occurring, what activities compose this approach, and how small-scale technology contributes to the American economic, social, and technological well-being. This paper is not an extensive, all inclusive dissertation on the subject nor does it take into consideration all arguments for and against innovation in small-scale technology. Rather, it is designed to be a "think piece," reflecting various ideas which have been expressed on an alternative approach to innovation as discussed in other chapters of this volume.

Innovation in Advanced Technology

The products and processes resulting from innovation have altered the American way of life throughout its history. Americans have progressed from an era where the major portion of a person's waking hours were spent in the factory to the service economy, based upon automation, where leisure time is made available by our dependence on machines and sophisticated technologies to complete tasks. This has augmented dependence on increasingly advanced, sophisticated technologies.

The present direction of U.S. innovation and technical development was determined in a period when labor was scarce and monetary and material resources appeared limitless. The current technologies which have been the basis of economic growth are capital intensive. The patterns of manufacturing and production are energy and resource intensive. The success of an invention is measured by the efficiency it engenders—the lease time and/or money spent in production or the time and/or money saved by utilization of the technology. This emphasis on efficiency has led to a dependence on mass production with its economies of scale, advanced technologies, and characetristics of centralized planning, automation, and rigidity (i.e., few adaptations to local needs and/or resources).

The increasingly sophisticated nature of technology has occasioned centralization in both decisionmaking and production. The interrelated qualities of the technological infrastructure and the myriad of inputs on which decisions have to be based, require policymaking on an aggregated level. Factors involved in mass production, economic efficiency considerations, industrial development, commercialization, and use of economies of scale all necessitate a centralized mode of planning on a broad scale. Also contributing toward the aggregation of the decisionmaking process is the esoteric nature and high degree of complexity associated with these technologies and the specialized expertise necessary for innovation.

The innovation environment has become basically technology driven. Products and processes are often developed because the know-how or expertise exists; because resources are available; or because "new" is believed to be better. This activity is variously described as "technology push" or the "technological imperative"—the development of technology because it is feasible. This is in contrast to "technology and/or demand pull," the development of technology to meet a specific need or to provide a solution to a defined problem. In the technology push situation, industry subsequently must create a demand for the new technology and convince the public that it is desirable, encouraging and promoting the (often wasteful) consumer society.

Changing Environments and Values

The lifestyles dictated by Western patterns of technology utilization have induced alterations in the environment which require further innovations and approaches to meet the changing needs of society. The factors which have led to the evolution of the current technological direction are beginning to change. Consequences of the use of these standard technologies have affected the technological milieu and have created new situational constraints on innovation and technology. The resource-intensiveness of the system has increased prices and depleted the store of inputs to production. The reliance on conventional fuel sources and the large amounts of energy consumed in the manufacturing and use of technology has led to declining availability, dependence on foreign nations, and the growing realization that many U.S. resources may be critically depleted in the near future.

The environment which promoted capital intensiveness in technology or the purchase of equipment cannot be considered a foregone conclusion. Capital for investment in innovation is increasingly expensive and scarce. Concurrently, labor has become relatively abundant and under- and unemployment is a continuing problem. Economic efficiency criteria for determining the value of the technology is being challenged. Technological innovation in automation to achieve efficiency is seen as a contribution to increased under- and unemployment and its concommitant social and economic problems. Unions continue to resist the use of technologies which replace the worker in the production process. Pride in individual craftsmanship and individual achievement again may become valued in place of mass production which has tended to induce boredom through repetition and the "I could care less" attitude of the factory employee.

Social, philosophical, and value concerns are in transformation and they are affecting the economic and technological condition. The movement away from the cities and back to the rural and semi-rural areas of the country reflects this situation. The back-to-basics philosophy which has accompanied this trend is a rejection of the notion that the most sophisticated and efficient method or technology is always the most desirable. Also of consequence are the environmental and social effects of technology. Symbiotic with this philosophy are various laws and regulations (such as air and water pollution requirements) which mirror society's concern for the environment and which demand new directions in technology.

Of interest to a large number of citizens is the control over the choice of technology. The forces of centralization which have been embodied in current technologies controlled largely by corporations are under scrutiny. While much of the decisionmaking associated with sophisticated products and processes must be made on an aggregate level due to their complex nature, there are forces pushing for more local and individual control over technology. Demand is increasing for technologies which can be operated and utilized by the individual consumer. This quest for expanding the choice of technology and decentralizing the process has spurred the interest in innovation for alternative, small-scale technologies and opened up a new field of invention for the entrepreneur.

Small-Scale Technology

New and different types of innovation are appearing in response to the various trends which are generating new requirements for technology. Events suggest that new approaches are enhancing economic and social well-being. Basic to this are so-called "small-scale technologies" which are being developed, accepted, and utilized in addition to the standard sophisticated technology which Americans have grown accustomed to. This type of technology is generally labor intensive, utilizes local materials, is relatively easy to maintain and repair, and requires minimal capital investment to acquire and operate. These technologies generally use renewable or abundant resources and are not destructive to the environment. Because of these characteristics, small-scale technologies often allow for self-sufficiency and decentralization, both in terms of decisions to use the technology, as well as in the actual utilization of the product or process.

Examples of appropriate technologies are numerous. They span the everyday range of activities from hot water heating and cooling of homes and businesses by solar energy, to integrated pest management on farms using biological methods as a substitute for chemical insecticides. Other appropriate technologies include tillage and cultivating equipment compatible with small tractors utilized on small family farms and anaerobic digestors to produce gas for fuel for heating and generation of electricity for production. Passive energy conservation methods—insulation and window placement—are also considered within the range of appropriate technologies, as are wind driven irrigation pumps and electrical generators.

Small-scale technology is not secondhand or left-over technology, nor is it ineffective because it does not utilize or create economies of scale or promote efficiency in the standard definition of the word. Small-scale technologies are new, innovative ways of developing and/or applying technology to meet defined needs ("technology pull"). They are "demand driven" as opposed to standard technologies which often appear to be "technology driven", as discussed previously. Thus, the crisis in conventional energy sources has established a need for new forms of energy and new manufacturing processes which utilize fewer or different fuels. Small-scale technologies such as wind and solar energy have been developed and are being utilized to heat and cool homes, dry crops, and generate power. Environmental problems associated with manufacturing have stimulated development of new small-scale technologies which have less adverse impacts in terms of pollution and resource use. Labor-intensive technologies generally do not generate the industrial waste which industrial technologies tend to accumulate. The demands of the small farmer, for example, have spurred innovation in farm tools and machinery which are within the financial and technical capabilities of the individual but which are also effective in preparing, planting, and cultivating crops. Human needs which have not been satisfied by mass-produced "high technologies" have encouraged the invention and development of new approaches, products, and processes.

Innovation in Small-Scale Technology and the Economy

The traditional processes, problems, and prospects of industrialization have been discussed elsewhere in this study. Many of these concern the amounts of time, money, and resources which must be committed and the concommitant risks invloved. Innovation of small-scale technology offers opportunities and advantages different from those generally associated with large-scale industrialization. The nature of small-scale invention as defined here provides alternative approaches and solutions.

Innovation in small-scale technology can be readily undertaken by the individual entrepreneur. It offers the chance to be creative without requiring a major commitment of resources. Lesser amounts of time and money are involved relative to industrialized technology because of the basic characteristics associated with small-scale technologies, including the use of low-cost, readily available materials and the emphasis on adaptation. This often reduces the amount of risk involved with innovation. In addition, the time frame of small-scale innovation is often shorter than that of standard technology, generally allowing for a quicker return on investment and a decreased amount of time between need definition and product commercialization or use. The extent of change and the time necessary to make adaptations are minimized as the level of technical sophistication is decreased.

The decentralized nature of small-scale technology and the innovations associated with it can be of major relevance to the patterns and promotion of economic growth. Small-scale invention is suited to the application of technology to local problems as needs are identified. The relatively noncomplex nature of these products and processes allow for small alterations as local conditions demand new technical approaches. This encourages decentralized decisionmaking. The adaptability inherent in these technologies encourages local or individual choice both in the technology and/or in the form of innovation to develop a new technology. The relative low cost, the relatively easy maintenance, and the reliance on new forms of application of technology, increase the number and range of technologies which are within the reach of the individual and increase the technical options, from which to choose.

Decentralization and self-sufficiency are further enhanced by innovation in the area of small-scale technology because there is no necessity for the specialization required to select, apply, and operate sophisticated industrial technologies. Decisionmaking has become concentrated in certain organizations and institutions in part because the extensive specialized knowledge necessary for utilizing standard technologies can be acquired only through high levels of training, often provided through those organizations or though expensive education. The relative simplicity of small-scale technologies and the ability of the owner/operator to provide upkeep and maintenance, however, makes such expertise relatively useless and increases the measure of self-sufficiency associated with the use of these types of technology.

Small-Scale Technology and the Public

The public is growing increasingly reluctant to accept the "technology-push" process of the industrialized, consumer society. Citizens are beginning to exert control over the choice of technology and, indirectly, over the direction of development. They are expressing environmental as well as economic and social concerns as these relate to the use of technology. The make-up of the consumer sector is being transformed. Government regulations and restrictions are increasing. Activities of the business sector, provider of capital and investment, are being modified. Big no longer exclusively means better. The growing frustrations involving technology and its apparent inability to provide a panacea for public problems have spurred an antitechnology attitude. But it has also encouraged the development of new types of technologies, of different products and processes which are responsive to changing societal attitudes and needs and which can serve as alternative methods and mechanisms for accomplishing an objective or performing a task. The increased demand for understandable technology; technology over which the individual rather that the specialist or corporation has control; technology which can reflect individual needs and the requirements of the local environment has created a growing interest and participation in small-scale innovation.

It must be recognized, however, that neither standard technologies nor small-scale technologies alone can address the economic and social requirements of a complex American society. While the concentration on industrialization spawned the back-to-basics movement, it has also brought us tremendous achievements in many areas. It is unrealistic to assume that the country would reject the benefits which industrialization, science, and technology have brought and substitute small-scale technologies. Yet, these alternative products and processes serve vital segments of the population and meet various defined social and economic needs. What appears to be necessary now is a balanced approach to technology—the support of innovation in all technical areas, large and small, that will offer a choice of mechanisms to achieve an objective or meet a demand. Through innovation and by broadening the store of a wide range of technologies at all levels of complexity, the United States can increase its chances of being able to meet society's needs while maintaining economic growth and development.

IMPLICATIONS

Governmental recognition of the commitment to and the extent of innovation in small-scale technology has been rather slow. The institutional mechanisms to promote innovation are generally directed toward highly sophisticated industrial technologies. Research on innovation also focuses on advanced technology, as do recommendations for an improved innovative environment. However, popular acceptance of the concepts and characteristics of the small-scale approach is forcing a reevaluation. While invention of this type may avoid many of the problems associated with industrial innovation, some of the issues are similar if not as extensive.

Small-scale innovation is a growing phenomenon. It is being performed despite the lack of recognition in many institutional circles. The issue raised is whether there is a role for the Federal Government to play in encouraging, promoting, and/or supporting invention of this sort. There is precedent for such activity, especially in the development of alternative energy technologies by small business. However, careful consideration is in order—too much Government regulation and intervention in the private sector is one of the major barriers to innovation. Too often, Government activity has unexpected, detrimental consequences.

What needs to be achieved is a way of assisting the entrepreneur in a manner which does not restrict his innovative inclinations and which nonetheless permits the timely commercialization of new, responsive technologies. Whether Government activity should be used to encourage this is still open to question. Yet, innovation is of benefit to the public only when it is available on the marketplace—an idea which cannot be commercialized assists no one. Technical, as well as financial, assistance through the Government or the private sector (possibly encouraged by an improved set of Government policies) can expand development of the small-scale technologies which have been able to satisfy many of the new and increasing demands of our society.

The United States is in a state of transition. It has moved from simple technologies, to complex industrial products and processes, to the uncertain position it now occupies. There are many indications that innovation is lagging. The Nation's economic outlook no longer looks as bright as Americans would like, and the country is having considerable difficulty meeting its societal needs. The United States cannot go back to the primitive technologies of pre-industrial existence—nor is the Nation able to address all of the new problems it has encountered with the application of more complex, more sophisticated technology. America needs a balanced approach—innovation in all areas of technology and on all levels of complexity. In this way, the store of available technologies from which to choose can be expanded, thereby increasing our chances of meeting the demands of American society through continuing economic growth and development.

INNOVATION IN PUBLIC TECHNOLOGY

By Wendy H. Schacht *

CONTENTS

Abstract

Public demands and Federal regulations are placing increasing responsibilities on State and local governments. Concurrently, budget limitations are constraining the amount of resources that these jurisdictions can spend meeting the needs of their citizens. One solution to this dilemma is to increase the productivity and effectiveness of public goods and services through the application and utilization of technology. This process—labeled "public technology" in the State and local sector—affords a mechanism to foster new innovation to supply solutions to State and local problems. Non-national jurisdictions, however, generally are not receptive to innovation. Compounding this situation, the State and local marketplace is characterized by a proliferation of policies, practices, and organizations which, when combined with an apparent lack of technical expertise, leads to a "no-risk" environment. Because of the absence of an aggregated market, industry has tended to avoid participation in the public technology venture.

The private sector remains apparently unconvinced that there would be a sufficient return on investment in technology specifically designed to meet the needs of these jurisdictions. To fill the gap between what States and localities need and what technological solutions are available, the Federal Government has created various technology transfer and technical capability building programs. Yet it appears that industry could be attracted to innovation in the State and local arena if markets could be identified and aggregated. This would encourage industry competition for new technological innovations to assist State and local governments to meet the needs of their constituents. The Congress, although interested in innovation, has not devoted extensive attention to the impact of the public technology market on the U.S. economic situation. Among the options

*This paper was prepared by Wendy H. Schacht of the Congressional Research Service and does not necessarily represent the views of the CRS.

available, Congress can provide technology transfer guidelines and support executive branch efforts to improve the technical capabilities of States and localities so that these jurisdictions can offer an additional outlet for innovation in industry.

The Public Technology Sector

State and local governments are experiencing unprecedented and increasing demands for the expanded provision of improved goods and services. Federal legislation has given State and local jurisdictions broad responsibilities in carrying out Federal mandates. At the same time that demands are expanding, budget cutbacks and worsening economic conditions in many areas are diminishing the amount of money and personnel available to meet these needs. In response to this, various initiatives involving the application of technology are being explored, proposed, and instituted to alleviate several of the constraints under which State and local governments find themselves. Among these activities are the transfer of technology from the Federal Government to non-national jurisdictions, technology transfer from the private to the public sector, efforts to improve productivity in State and local units, and the development of an increased innovative capacity in non-Federal Government organizations.

Many State and local officials are looking for technological solutions to the myriad of problems confronting them. This search has led to the rise of "public technology"—the adaptation and utilization of new or existing technology to public sector needs. The application of technology to State and local services is a complex and intricate procedure which encompasses many variables, but the crucial element is the actual utilization of the technology. Technology transfer is the process whereby States and localities can acquire technology useful or necessary for the more expeditious provision of public goods and services. The utilization of this technology may be the basis for improved governmental productivity and service effectiveness through innovation—the creative use and application of technology. The public technology endeavor is a mechanism to foster new innovation necessary to supply solutions to State and local problems and to meet new and revised requirements for goods and services.

The innovation process at the State and local level mainly involves the technology transfer process culminating in the application and use of technology. Technology transfer is the activity whereby a product or process developed in one area is utilized in another area or for another purpose. The transfer of technology from the public to the private sector or vice versa, from one governmental unit to another, or from industry to industry enables technologies to provide benefits beyond those incurred in their original usage. In a general sense, technology transfer in the State and local sector is accomplished through one of three processes.

First, technology in its original form can be transferred from one governmental unit to another or from industry to government and utilized for identical purposes. Second, the technology may be applied to a different purpose while retaining its original construction or components. Third, the technology may be adapted for application to new and different situations and environments.

Although it might appear logical that the public technology area should have attracted the interest of the private sector, certain factors currently associated with the operation of State and local governments have caused industry to remain aloof from this area. In view of the lack of industry involvement, the development and "marketing" of technology designed for State and local government use have occasionally been undertaken by the Federal Government. Federal departments and agencies have created various programs and activities designed to foster sub-national technology transfer, technology utilization, and innovation. This report outlines the Federal response to State and local technical needs—including both hard (for example, equipment) and soft (for example, systems programming) technology, the State and local marketplace, and the view from private industry. The underlying assumption—discussed in detail later—is that States and localities can provide a new, virtually untapped market for private industry ventures into new technological innovations designed to meet the needs of non-national jurisdictions, if and when, the present barriers to such activity are removed.

The Development of a Federal Approach to Public Technology

For more than a decade, policy issues and considerations relevant to the intergovernmental utilization of science and technology have been a subject of concern in the Executive Office of the President, certain Federal departments and agencies, the Congress, and State and local organizations. The increasing demands on State and local governments for the provision of more goods and services have been accompanied by a recognition on the part of Federal, State, and local officials that increased technical assistance is necessary to meet these needs. Because of the resources available to it, the Federal Government has become the main focus for assistance to non-Federal jurisdictions. Yet, policy formulation with regard to the transfer of the results of Federal research and development to States and localities has proven to be a difficult task. Despite this activity, there is neither a delineated policy nor established guidelines for the intergovernmental transfer of technology.

A variety of activities have been undertaken to foster utilization of Federal research and development results. In March 1972, President Nixon addressed Congress on science and technology. In his statement, Mr. Nixon announced a new effort to support and utilize science and technology for the improvement of the Nation's economy and its quality of life. He called for new "partnerships" between Federal institutions, private industry, State and local governments, universities, and research organizations to apply R&D results to civilian needs. Observing that "Federal research and development activities generate a great deal of new technology which could be applied in ways which go well beyond the immediate mission of the supporting agency," former President Nixon said that States and localities need to play a central role in the decisionmaking process surrounding the application of these technologies.

These concerns were further delineated in a series of reports which appeared around the same time and which first introduced the "public technology" term. These studies, including *Power to the States, Mobilizing Public Technology,*[1] *Intergovernmental Uses of Federal R&D Centers and Laboratories,*[2] *Public Technology, A Tool For Solving National Problems,*[3] and *Action Now: Partnerships—Putting Technology to Work*[4] called for a new effort to apply technology developed in the public and private sectors to the pressing needs of States and localities. Among the options discussed were the intergovernmental transfer of technology and technical expertise from the Federal Government to State and local jurisdictions as well as various cooperative private and public efforts.

In response to various recommendations made in these reports, several Federal programs for technology transfer and utilization have been implemented. In addition to specific departmental or agency efforts, the National Science Foundation has established various cross agency activities. Under the Intergovernmental Science and Public Technology Program, NSF assists in developing and building State and local science and technology capabilities. In doing so, the Foundation supports several networking organizations and regional innovation groups to broker between State and local officials and the technical community. One of these efforts, Public Technology Incorporated, was created to assist in technology identification adaptation, and application. Also serving similar functions, and funded by NSF, are the Community Technology Incentives Program, the Urban Consortium, and the Urban Technology System.

One of the most successful programs to promote the effective utilization of technology developed within the Federal Government is the Federal Laboratory Consortium for Technology Transfer. With a voluntary membership of approximately 180 Federal laboratories, the Consortium establishes channels of communication and interaction between agencies and potential users at the State and local levels. These networks create the means through which user (that is, State and local government) requirements can be identified, delineated, and addressed in light of the increasing demands on non-national jurisdictions. The Consortium involves the user community in the research and development endeavor and provides technical and project assistance to States and localities to ensure effective utilization of technological resources.

A major recent initiative in the intergovernmental technology transfer effort is the Intergovernmental Science, Engineering, and Technology Advisory Panel (ISETAP) within the Office of Science and Technology Policy. Established by the National Science and Technology Policy, Organization, and Priorities Act of 1976, ISETAP was mandated to identify and promote Federal programs to increase State and local utilization of federally funded R&D. Located within the Executive Office of the President, the Panel has the responsibil-

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[1] Council of State Governments. Power to the States, Mobilizing Public Technology. Lexington, Council of State Governments, 1972.

[2] Arthur D. Little, Inc. Intergovernmental Uses of Federal R&D Centers and Laboratories. Report to the Council of State Governments. Washington, Arthur D. Little, Inc., 1973.

[3] Federal Council for Science and Technology. Committee on Intergovernmental Science Relations. Public Technology, a Tool for Solving National Problems [1972].

[4] National Action Conference on Intergovernmental Science and Technology Policy. Action Now: Partnerships—Putting Technology to Work. Harrisburg, Pennsylvania Office of Science and Technology, 1972.

ity for determining methods and mechanisms, both existing and potential, which will ensure that the scientific and technological needs of non-national governments are incorporated into the decisionmaking processes of Federal departments and agencies. In pursuit of these objectives, the efforts of ISETAP are concentrated on: (1) building into the Federal decisionmaking process a method to assess State, local, and regional needs; (2) advancing the scientific and technological capabilities of State, regional, and local jurisdictions; (3) expanding the use and adaption of already existing technology at the non-national level; and (4) improving the transfer of information and technical expertise in a manner conducive to utilization.

Attempting to outline his administration's policy in this area, President Carter, on February 25, 1977, issued a memorandum for the heads of executive departments and agencies directing them to involve State and local officials in the development of the Administration's policy and budget priorities and programs. The President noted that the non-national jurisdictions deliver many of the services that the Federal Government supports; that State and local officials can present necessary perspective on program effectiveness and feasibility; that early participation in the Federal program planning process develops broad-based support; and that cooperation can ensure that national programs and priorities parallel needs at the State and local level. Mr. Carter thus directed that a description of the agencies' actions to meet these objectives be included in any major Federal policy or reorganization proposal.

Current Federal Activities

Technology transfer as practiced by Federal departments and agencies is a many-faceted endeavor based upon the idea that the results of federally developed R&D can be applied, in this case, to the problems of States and localities and used to increase the productivity and quality of public services. A variety of approaches have been tried; some on a formal, programmatic basis, others in informal, ad hoc arrangements. All are operated to encourage and promote the movement of innovations into the State and local milieu.[5] These several approaches can be partially characterized by the emphasis they place on the evolution of the technology transfer process. Part of the Federal effort is designed to increase the capacity of States and localities to make technological decisions and to understand the relationship of science and technology to their problems. Technical assistance and research utilization efforts are directed at enabling officials to define their problems and assess alternative technological solutions. These activities are seen as supporting the "demand-pull" mode of technological development. Technology is transferred, adapted, and utilized to meet a specific need or to provide a solution to a defined problem. Programs which stress scientific and technical capacity building, technical assistance, and research utilization provide the techniques by which State and local officials can create the demand for new technological innovations.

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[5] U.S. Congress. House. Committee on Science and Technology. Subcommittee on Science, Research, and Technology. Domestic Technology Transfer: Issues and Options. (Committee Print) Washington, U.S. Government Printing Office, 1978, p. 149.

On the other hand, Federal technology transfer programs which seek to find secondary applications of technologies developed in the process of meeting Federal responsibilities tend to deal with the "technology-push" mode of technological development. These efforts, generally called "spin-off," are an attempt to take available technologies and find problems to which they can be applied. Often it means that technologies are selected because they are feasible, not because there is any perceived demand.

Within Federal departments and agencies, various mechanisms have been developed to promote and support the intergovernmental transfer process, including: direct technical assistance; information dissemination; training; joint projects, funding, and management; and demonstration programs. Most agencies' technology transfer efforts involve a combination of methods to ensure secondary (or beyond) utilization of the results of federally funded research and development. The choice and mix of mechanisms are based upon each department's experience, constituency, organizational structure, authority, and resources for this function.

It is generally accepted that the most effective method of transferring technology and technical expertise is from person to person. This form of transfer allows for problem solving through issue definition, discussion, and adaptation as direct contact is made between State and local officials and Federal agency personnel. Supplementing this activity in most Federal departments is information dissemination, perhaps the most prevalent form of transfer. All Federal units publish, distribute, and make public the results of portions of their research and development efforts. The information dissemination process is generally not limited to distribution systems and responses to written requests. Publication in professional journals, workshops and seminars, training programs, and direct technical assistance are frequently used in conjunction with document distribution.

Technology transfer is often effected through training. This mechanism allows for personal interactions and the direct communication of knowledge through first-hand experience and teaching. It is designed to provide for capacity building by increasing the understanding of a technology or technological process and its application. Cooperative efforts, joint funding, and research management are additional methods used by Federal departments and agencies to encourage technical utilization and thus effect technology transfer. By providing funding and engaging in joint management of a technical program or project, the Federal agency can promote the utilization of technical solutions, provide for the expansion of State and local capabilities through cooperative activities and interaction, and provide resources enabling these jurisdictions to adapt technologies suited to their needs. Demonstration projects, by illustrating that a technology or technological process works in an actual situation, are intended to stimulate further acceptance and utilization by States and localities. Field testing supported by Federal agencies furnishes a method by which non-national jurisdictions can see the results of technological applications without having to invest in untried activities.

THE STATE AND LOCAL MARKETPLACE

The public technology concept developed partially in response to the relative absence of private sector interest in developing and marketing technology designed to State and local specifications. Numerous factors contribute to this situation; particularly those issues associated with the apparently widespread lack of State and local governments' receptivity toward innovation. There traditionally has been an aversion at the State and local level toward new technology and a slow pace of incorporation of innovations into the operations of governmental services.[6] This has led to the idea that productivity in the provision of State and local services is lower than it could be.[7] The motivations to improve productivity inherent in the private sector—that is, competition, and profit—are not found in these jurisdictions.[8] Yet increased efficiency is necessary if State and local governments are to be able to continue to function and meet their obligations under budget constraints. Innovative ideas, therefore, are required if technological application is to increase the return on expenditures for public goods and services.

The field of innovation in State and local government has attracted many researchers and has developed a language peculiar to the endeavor. Various studies have identified how and why State and local jurisdictions apply and integrate technology in their operations and the barriers to this process. Models of innovation in these units of government have been developed which break down and identify various stages associated with the innovation process. The most common model appears to be the two stage model, which involves initiation and implementation.[9] Other researchers have identified three stage models: Support; implementation; and incorporation (Berman and McLaughlin); and four stage models: Prior state; initiation; implementation; and routinization (Yin). Lambright identified a different four stage model of the innovation process which stressed the time element and included pre-adoption, adoption, implementation, and incorporation.[10] Taking the idea a bit further, Eveland et al. have proposed a five stage model which involves agenda setting, matching, redefining, structuring, and interconnecting.[11]

What these models attempt to depict, despite their different approaches, is the movement, over time, of an idea to implementation. They identify the decisionmaking environment. In the case of the State and local sector, innovative behavior requires the perception of a need plus a series of events culminating in the utilization of a product or process—the crucial element in innovation.

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[6] Feller, Irwin. Diffusion and Utilization of Scientific and Technological Knowledge within State and Local Governments. University Park, Pa., The Pennsylvania State University, February 1979, p. II–1.

[7] U.S. General Accounting Office. State and Local Government Productivity Improvement: What is the Federal Role? Washington, U.S. Government Printing Office, Dec. 6, 1978, p. i.

[8] Ibid., p. iii.

[9] Discussion based upon: Eveland, J. D., Everett M. Rogers, and Constance Klepper. The Innovation Process in Public Organizations. Ann Arbor, The University of Michigan, Department of Journalism, March 1977, p. 63.

[10] Lambright, W. Henry. Principal Investigator. Adoption and Utilization of Urban Technology: Decision-Making Study. Executive Summary. pp. 7–9.

[11] Eveland, J. D., Everett M. Rogers, and Constance Klepper. The Innovation Process in Public Organizations. Executive Summary. Ann Arbor, The University of Michigan, Department of Journalism, March 1977, pp. 10–14.

Yet, regardless of the number of stages chosen to represent the innovation process, the studies consistently indicate that State and local governments are not particularly receptive to innovation and the adoption of new technologies. Certain factors inherent in the political process apparently mitigate against innovative activities. Budget constraints are such that States and localities cannot afford to spend money on products or processes which are untested, unproven, and may not produce the desired results. New technologies are expensive because of high development costs and small markets. Added to this is a reluctance to spend for new products and processes to replace old technologies which, while not efficient, are nonetheless in operating order.

A 1976 study by RAND found that when bureaucracies do innovate, it appears to be:

> . . . more as a function of the opportunities for bureaucratic growth, status, and power than merely as a function of the need to improve services. Thus, even though a particular innovation can improve services, if it does not serve bureaucratic goals it is not likely to be incorporated.[12]

It often appears that efficiency and effectiveness of public services are sacrificed to political considerations perceived to be more important. These barriers to innovation are perpetuated because, in part, there are few incentives built into the system to promote and reward innovation and the creative utilization of technological alternatives.

State and local officials often lack the technical expertise necessary to make informed decisions between technological alternatives. An apparent absence of an appreciation and understanding of science and technology and the role they can play in meeting many of the needs of non-national jurisdictions often shapes the decisionmaking environment. This tends to create situations where a communications and awareness gap evolves between State and local representatives, technically oriented industry, and the scientific community so that joint efforts at problem solving are often infrequent and difficult.

The definition of requirements is the primary step in choosing new products or services, however, State and local officials reportedly are often unable to identify problems adequately and to reach agreement on priorities and goals. Compounding this difficulty is the realization that there are generally no clear cut problems or solutions and that trade-offs must be made within a decentralized and diffused decision-making process. Criteria for evaluating technological efforts often are also unavoidable, thus perhaps rendering choices personal or political rather than analytical.

Officials at the State and local level tend to be primarily interested in activities which have short term, highly visible payoffs; ones which can be identified as having brought immediate benefits to the area. Effective technical applications, however, often require a longer time span to ensure productive utilization and therefore do not provide politicians the opportunity to take advantage of any benefits which accrue. Thus, the "quick fix," and often cosmetic solution tends to take precedence over longer range applications of technology.

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[12] Yin, Robert K., Karen A. Heald, Mary E. Vogel, Patricia D. Fleischauer, and Bruce C. Cladeck. A Review of Case Studies of Technological Innovations in State and Local Services. California, the Rand Corp., February 1976, p. ix.

The View From Private Industry

There are often insufficient economic incentives for private industry to operate in the State and local marketplace.[13] While States and localities theoretically present a large, untapped market for many technological innovations, there have been few successful efforts at identifying and aggregating the needs of these potential customers. Numerous, and often conflicting, technical specifications and procurement policies across State and local units present complications for industry in trying to develop prototypes which would meet the varying requirements of individual jurisdictions. Apparently, concurrent and overlapping needs have not been accumulated in such a manner that could present a viable market which would justify research and development expenditures by industry.

Technology transfer from industry to States and localities requires market evaluation and the identification of a business opportunity. Products must be identified which can address the problems and evaluations must be made concerning the potential benefits to be accrued by industry in serving the market—the expected returns on investment. State and local decisionmakers themselves have traditionally incurred problems in defining their problems and understanding which solutions would be the most viable. Elected or appointed officials are often unfamiliar with technology and the technological milieu; nor is marketing an overriding consideration. This often results in a divergence of purpose and interests between the technologically based, market-oriented industry and the State and local users.

Procurement practices of States and localities vary between and within jurisdictions, but are based primarily upon awarding contracts to the lowest bidder. Life-cycle costing and performance evaluations are generally ignored in the decisionmaking process. This makes marketing of new, innovative technologies especially difficult and requires industry to approach each unit of government with a different strategy. Such activity adds substantially to the cost of a product and serves as a barrier to private involvement in the public technology market. Thus, instead of being utilized as an incentive for innovation, the proliferation and composition of procurement policies in non-national jurisdictions have dampened the creation of a viable technological market which would encourage industrial innovation to meet State and local needs.

As the State and local procurement arena is now structured, industry is placed in a position where it must convince officials of the benefits to be derived from technology utilization and must often deal with collective decisionmaking by nonspecialists. Combined with a lack of need definition, this tends to create a "technology-push" situation in which industry tries to sell its off-the-shelf technologies by finding and identifying what it sees as a State or local need. This is in contrast to the "demand-push" concept where user (that is, State and local) needs are defined by the implementing jurisdiction and new technologies are developed or adapted to meet these needs. In either case, innovation can result if technology application and utilization are accomplished. The present situation, however, mitigates against such innovation since user needs have not been adequately identified and aggregated and industry

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[13] Feller, op. cit., p. II-5.

has found it economically disadvantageous to spend time and money convincing States and local jurisdictions of the benefits of technology.

A POSSIBLE FUTURE OF INNOVATION IN PUBLIC TECHNOLOGY

Federal regulations and public demands are placing increasing responsibilities on State and local governments. At the same time, budget considerations are constraining the amounts of time and effort these jurisdictions can spend to meet the needs of their citizens. The most obvious solution is to increase the productivity, effectiveness, and efficiency of public goods and services. But the mechanisms to accomplish this are not as apparent. Technological innovation is one method to do this. Yet, State and local governments have developed inherent barriers to innovation, including internal resistance, organizational fragmentation, and lack of analytical and technical capabilities.

The public technology market in States and localities is characterized by a proliferation of policies, practices, and organization which have led to inefficiency and decreasing productivity as new demands for goods and services are formulated. There is an evident lack of funding for both research and development and products designed to meet State and local specifications. The apparently low level of technical expertise exhibited by many State and local officials places decisionmaking within a consumer group (the States and localities) which cannot make informed choices based upon technical criteria in addition to political needs. This is reflected in the "no-risk" nature of most State and local marketplaces—an attitude which generally precludes the search for, and the introduction of, innovations.

Industry has generally avoided extensive involvement in public technology. The private sector has apparently not been convinced that catering to State and local jurisdictions would result in a sufficient return on investment. Since these non-national governments have been unsuccessful in aggregating their own need, industry generally finds itself without a market for innovations specifically targeted for States and localities.

The Federal Government has attempted to move into the breach between what States and local units need and what technological solutions are available. Federal departments and agencies have created various technology transfer activities to promote the application and utilization of federally developed technology for State and local problem solving. Efforts are also underway at building technical support capabilities to assist State and local officials in making technological decisions and in understanding technical choices. Federal programs can provide an impetus for innovation in State and local activities and stimulate the acceptance of technical solutions to problems. Funding, testing, and demonstration projects can act to cushion the risks associated with technological change. Efforts designed to accomplish market aggregation can lead to a more attractive environment for industry involvement. Yet, Federal activities must be evaluated as to all intended and unintended consequences. As Roessner points out:

> Federal regulations and support for standardization are two-edged swords with respect to their influence on technological change. They may increase market aggregation but, in the case of regulations accompanying categorical grants, they serve multiple values such as ensuring lowest purchase price and preserving jobs. In the case of federal promotion of standards, the positive effects of increased market size and aggregation may be offset by the need for manufacturers to

ensure that proposed new equipment will conform to existing standards. Unless standards are written in performance terms, this creates additional uncertainty and increases the cost of innovation.[14]

Except for ISETAP and occasional identified programs in specific agencies (for example, NASA), Congress has basically left the executive branch to its own decisions concerning technology transfer and utilization programs for State and local government. As noted previously, there is no national policy for the intergovernmental transfer of technology, nor is there any congressional direction regarding private industry involvement in the State and local marketplace. The inability of many Federal programs to identify, assist, and support State and local decisionmaking in the technical arena may encourage a reevaluation of executive and congressional, as well as industry, efforts to encourage innovative solutions. While Congress has recently undertaken to study the state of innovation in the American economy, it has not devoted major attention to the impact of the State and local marketplace on innovation and our overall economic situation. Among the options available, Congress can act, through legislation, to establish intergovernmental technology transfer guidelines and support executive branch efforts for technology utilization. The investigative and oversight functions also allow Congress to monitor Federal transfer activities and assistance provided State and local governments for developing their scientific and technical capabilities. This is one method to determine programmatic impact and ascertain alternative strategies for innovation in the public sector. Although the situation being dealt with here differs from general considerations relevant to innovation in the American economy, State and local governments—the public sector—provide an additional outlet for innovation in industry.

Beyond what Congress and the executive branch agencies can accomplish, institutional changes in State and local governments are necessary to improve the relationship between these jurisdictions and industry. Incentives and rewards for innovative behavior and a longer term planning outlook are needed to establish a receptivity toward science and technology and technological solutions to State and local concerns. Uniformity of State and local policies and procurement procedures, combined with a more centralized decisionmaking process, should make it easier for industry to work with these units to develop innovative ideas.

The activities designed to improve State and local decisionmakers' comprehension of science and technology should be critical to the acceptance and institutionalization of innovation in the provision of public goods and services on the non-national level. Once State and local officials can define their needs relative to technology and can accept the precepts of innovation—that new and creative application and utilization of technology can improve the efficiency and effectiveness of services—perhaps the State and local market will become better defined. Identified and aggregated markets will be attractive to industry. This should encourage competition, spark the profit motive, and give added impetus to the innovative process in the private sector as it attempts to find new solutions to the problems facing State and local governments and the people they represent.

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[14] Roessner, J. David. The Local Government Market as a Stimulus to Industrial Innovation. Draft speech prepared for delivery at the Workshop on Government Demand as an Instrument Innovation in Industry, Dublin, Ireland, June 6–7, 1978, p. 20.

SCIENCE AND TECHNOLOGY OUTLOOK RELATED TO ECONOMIC CHANGE

By William Boesman*

CONTENTS

*Specialist in Science and Technology, Science Policy Research Division, Congressional Research Service, Library of Congress.

Abstract

This paper is an attempt to set forth a preliminary structure for a comprehensive Science and Technology Outlook, particularly as science and technology relate to economic change. It analyzes the factors likely to be involved in science, technology, and economic change over the near-term future, that is, over a period of time beginning about 5 years in the future and extending 15 to 30 years in the future. The approach is fivefold: to examine the systemic factors involved in the Nation's scientific-techno-economic-socio-political system; investigate the total systemic "environment" in which the national science and technology system operate; identify some emerging technological developments which may be particularly important in the near-term future; review basic assumptions, an often neglected task in policy analysis; and analyze the preliminary findings and suggest

policy alternatives. Considering basic assumptions first—three scenarios incorporating alternative sets of basic assumptions are developed.

The "extrapolative" scenario is probably the most likely and preferable of the three presented in this analysis, although it includes significant existing and emerging problems. Thus, national science and technology policy alternatives are likely to be developed around this basic scenario, or a similar one, either implicitly or explicitly. The thrust of the extrapolative scenario is that the principal parameters of the global (or, at least, American) socio-politico-techno-economic system will remain fairly constant over the immediate and near-term future, that is, for at least he next 30 or so years. Another way of saying this is that the future will be characterized mainly by extropolations of existing trends. Two alternative scenarios considered for comparison are the "changing values" and "discontinuity" scenarios. Assuming the general validity of the extrapolative scenario, the national science and technology system may be called upon to contribute in a global context, to the solution of most of the 14 major world problem areas discussed in the report. In the activistic, dynamic society envisioned in the extrapolative scenario, none of these 14 major world problem areas is likely to be ignored and the following ones are largely to be particularly emphasized:

World population growth and aging populations.
Food: agricultural production and distribution.
Foreign affairs and military security.
Techno-economic security and viability.
Energy.
Health and biosciences.

Likewise, under an extrapolative scenario, all of the ten representative emerging technological developments discussed in the report, and many more, are likely to receive increasing attention and programmatic support from both industry and Government. The ten technological developments discussed are:

Birth control.
Food: aquaculture.
Health: combating future cancers.
Biosciences and bioethics: DNA.
Microelectronics: computers and telecommunications.
Transportation: short-hop STOL airlines.
Technology-abetted political participatory systems.
Energy: oil shale.
Energy: fusion.
Space colonization.

Finally, under an extrapolative scenario, two organizational policy alternatives are likely to receive increasing attention at the Federal policymaking level. These are:

Further development of the Federal science and technology policy and management structure; and

Further development, and perhaps institutionalization, of the Nation's analytical foresight capabilities and of effective linkages between those capabilities and science and technology policymakers.

To investigate these factors comprehensively, thoroughly, and continuously probably would require the institutionalization of the Science and Technology Outlook at the Federal policymaking level.

I. Introduction

This paper is a preliminary analysis of the factors likely to be involved in science, technology, and economic change over the near-term future, that is, over a period of time beginning about 5 years in the future and extending 15 to 30 years in the future.[1a]

A. Scope of the Study

This analysis has been undertaken as a contribution to the Joint Economic Committee's Special Study on Economic Change (SSEC). Ten major subject areas have been examined as a part of the SSEC, including "Research and Innovation." This paper, an examination of the outlook for science and technology, is a part of the "Research and Innovation" area study.

"The underlying thesis of the [SSEC] is that economic, social, political, international, and technical conditions have changed, and are still changing markedly."[1b] Consequently, the scope of this analysis covers science and technology trends, events, questions, and issues relevant to the functioning of the national economy in its global context. Specifically, the analysis deals with:

The internal (to science and technology) and external (societal) driving forces which affect the future, near-term (5 to 15 year) development of science and technology;

The broad science and technology (S&T) trends, that is, the complex of forces (like the existing anti-technology trend), which result from S&T-related activities; and

The major problems and opportunities generated from scientific and technological advances, particularly those related to economic change, with which the Nation and Congress will be faced in the near-term future.

The approach taken in this analysis is to identify those factors which must be considered in a comprehensive and systematic Science and Technology Outlook. Factors internal to science and technology are examined as well as those external factors which impact on science and technology. The report concludes with a brief discussion of the outlook for science and technology as it relates to economic change and some possible options for science and technology policymakers.

B. Definition of the Time Period Involved in a Science and Technology Outlook

For purposes of this analysis, a time period beginning in about 5 years and extending 15 or 30 years is considered to be the "outlook period" of the Science and Technology Outlook. There is nothing rigid

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[1a] Walter Hahn, Senior Specialist in Science Technology, and Futures Research of the Congressional Research Service proposed the writing of this paper and contributed to its outline and development.

[1b] Bolling, Hon. Richard. Opening Statement on the Special Study on Economic Change. May 31, 1978: 1.

about using such a time period for a Science and Technology Outlook, however, the elimination of the next five years from explicit consideration is important in order to obviate the danger of placing primary emphasis on the immediate future. It is probably true, in terms of science and technology at least, that the next five years already have been determined largely by science and technology policy decisions made in the past. What can be done now and in the immediate future is to further develop and use foresight techniques and processes for "alerting" purposes; conduct futures-related research of the 5-to-30 year outlook period; formulate appropriate options, policies, and plans based upon such research; and act, through the political process, to carry out such policies and plans over the next 5 years or so.

Thus, the time emphasis in this Science and Technology Outlook is beyond five years—15 or even 30 years in the future. This is the period in which current science and technology policies probably can make their greatest contributions—if science and technology policy analyses are sound and comprehensive, and if there are effective management linkages between such science and technology policy analyses and policymakers.

C. The Report Structure

Chapter II discusses those factors internal and external to the national science and technology "system." For example, science and technology education is discussed as an important internal S&T factor and political and governance factors, such as regulation, are discussed as external factors that impact significantly on the "science and technology system."

Chapter III sets forth a taxonomy of major world problem areas that probably should be addressed in a comprehensive science and technology outlook—from, for example, world population growth to the problems associated with human settlements. This section is an attempt to investigate the outlook for science and technology, not from its systemic components, but from another dimension—its role in a global context as a contributor of solutions to major world problems that likely will face the Nation and the world in the years ahead irrespective of the development of the national science and technology system.

Chapter IV sets forth several emerging areas of science and technology, driving or deriving from the factors discussed in the two preceding chapters, which seem to be particularly likely candidates for in-depth forecasts and impact analyses because of their potential as either major problems or opportunities. Examples range from birth control techniques through space colonization. There are hundreds of specific emerging technologies that could be examined beneficially, of which those given in this section are only representative for purposes of discussion.

Chapter V is a discussion of basic assumptions. Every analysis has basic assumptions, whether explict or implicit. This section sets forth three alternative narrative scenarios which incorporate sets of basic assumptions useful for developing a Science and Technology Outlook.

Chapter VI is the Analysis and Outlook Section of the paper. It sets forth (1) an analysis of the complex of forces resulting from the interrelationships among the many factors discussed in the preceding sections, and (2) a brief discussion of the outlook for science and technology as it relates to economic change and some possible options for science and technology policymakers.

D. The Science and Technology Outlook Process

"Science and Technology Outlook Related to Economic Change" is a part of a continuing Congressional Research Service (CRS) effort to develop an ongoing Science and Technology Outlook process. This process when completed will include the maintenance of files of futures-related information on issues of concern to the Congress; informal liaison with CRS and outside science and technology and other subject specialists; an interdivisional CRS Foresight Team of subject specialists; a Futures Information Retrieval SysTem (FIRST), which will include an in-house futures research capability plus a computer information storage and retrieval system of futures information; and related activities.

These capabilities are being integrated into an ongoing process to more efficiently support the preparation of futures-oriented reports and analyses like this one which may be required by the Congress.

II. Systemic Factors in Science and Technology as Related to Economic Change

A. Introduction

There are many factors which comprise the Nation's science and technology system. These "systemic factors," and how they will relate to economic change in the future, can be analyzed in several ways. The method chosen for this analysis is to discuss these systemic factors first in terms of science and technology itself (in terms of those forces internal to science and technology) and then in terms of what may be called generally the external or societal forces driving, or the ambient influencing, the science and technology system from the "outside."

This chapter deals with science and technology first and, because education is so basic to science and technology, with scientific and engineering education first of all. The chapter subsequently deals with those "external" economic, political, societal, and environmental factors that will impact on, or drive, science and technology from the outside.

Any characterization of a problem or opportunity as "scientific" or "economic" or "societal," generally oversimplifies and thus distorts somewhat the issue under investigation. For example, most "scientific" issues have, and will continue to have, "economic" or "societal" ramifications. For purposes of presentation and discussion, such characterizations do serve a useful purpose, so long as it is understood that they are meant only to be labels and not ironclad compartments.

B. Education in Science and Technology

Education will be one of the most important aspects of the outlook for science and technology as related to economic change. The optimization of science and technology [2] would not require universal education, because not everyone is educable in, or has an aptitude for, science and technology. But the optimization of science and technology would require universal education of qualified persons. In the United States, society's leaders do not act in a concerted fashion to optimize science and technology; other priorities, generally unarticulated, take precedence. Competing societal priorities, influential interest groups, individual personal preferences, and relative availabilities of financial resources generally govern how many and what types of persons will be educated in science and technology and what fields of science and technology will be supported.

How many persons should be educated in science and technology is a value judgment that perhaps cannot be answered adequately today—or ever—by political and educational decisionmakers. To a first approximation, however, improving science and technology education (increasing the number and quality of students and the number and quality of courses) generally will improve science and technology in quantifiable ways, such as the number of Nobel Prizes awarded to U.S. scientists per unit of time, or the international balance of trade in technological products.

Education, broadly defined, will be extremely important in fostering science and technology through the conduct of basic research. Over 50 percent of basic research is performed by universities and colleges (although many of the funds so expended are supplied by the Federal Government and other sources). About another 10 percent of basic research is performed by Federally Funded Research and Development Centers (FFRDCs) administered by universities and colleges or consortia of universities and colleges. The cutting edge of science and technology, basic scientific research, in large part resides in, or is significantly influenced by, the Nation's educational establishment. This is likely to continue in the future.

Engineering education is likely to be just as critical to the Nation's economy as education in the sciences. The industrialized nations of the world compete with each other in high-technology products, like electronics, and in technological processes, like steel making. If the Europeans and Japanese are out-competing the United States in the economic production of such technological products and processes—and if the Europeans and Japanese are not innately more intelligent or competitive than Americans—the difference must be in the total science and technology-economic-environmental-political-societal ambience in which American industry operates. An important factor in this regard is the quantity and quality of scientific and engineering education per capita of the population and the related use of scientists and engineers in civilian research and development.

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[2] The "optimization" of, and to "optimize," science and technology, as used on this and succeeding pages, means essentially to "maximize the effectiveness of" science and technology, or where maximization is not feasible or appropriate, to "satisfice." "[Satisfice] is an activity of 'administrative man' who looks for a course of action that is adequate, reasonably satisfactory, or 'good enough.' It may be contrasted with 'maximize,' an activity of 'economic man' who selects the best alternative from among those available. Examples of satisficing criteria familiar to businessmen are 'share of the market,' 'adequate profit,' and 'fair price.' A significant aspect of satisficing behavior is that administrative man, because he satisfices rather than maximizes, can make his choices without first examining all possible behavioral alternatives and without ascertaining that these are in fact all the alternatives." From Herbert A. Simon. Administrative Behavior. New York, The Free Press, 1957: xxiv and xxv. In U.S. Congress, House, Committee on Science and Technology. Subcommittee on Science, Research, and Technology. Science Policy: A Working Glossary [Fourth Edition—1978]. Committee Print, 95th Congress, 2d session. Washington, U.S. Government Printing Office, 1978: 76.

As discussed in the following sections of this analysis, an increasing number of areas of U.S. science, technology, and techno-economics are facing increasing competition from foreign nations, particularly Japan and western Europe. Perhaps this is also true of the Nation's educational capabilities. Just over 10 years ago, Peter Drucker could say with confidence:

> Education is the one area, therefore, in which the richest of all societies, the United States, has a genuine advantage—provided it can make the knowledge [essentially the professional, "white collar," or office] worker productive.[3]

A basic issue for science and technology policymakers will be whether this statement is still true or whether the United States is losing its one "genuine advantage" and, if so, what can be done about it.

A current issue of concern to the science and technology community is the Administration's proposal to create a separate Department of Education and incorporate therein major parts of the educational support activities of the National Science Foundation. There is widespread concern that this type of reorganization would dilute and weaken the Nation's support for higher scientific and engineering education in the future.

If the Nation's total potential capability in science and technology can be likened to a reservoir of water, the educational establishment can be likened to the valve or spigot that will regulate the flow of that resource to society according to its needs.

C. Factors Internal to Science and Technology

1. BASIC RESEARCH

No one can predict or program fundamental discoveries in basic science, the so-called scientific "breakthroughs." But without such breakthroughs, science and technology will become mainly incremental, and the improvements, innovations, increased industrial productivity, and other second order effects of basic scientific research will remain marginal. Adequate financial support of basic research is therefore based upon a blend of faith and historical evidence that such scientific breakthroughs will occur occasionally when basic scientific research is carried out diligently. Such fundamental breakthroughs in the sciences provide opportunities for generations of scientists and engineers to develop new ideas, processes, and products for continued economic growth.

National support of basic research will total about $6.7 billion per year in 1979.[4] Whether this is enough support to provide for continued U.S. leadership in scientific research, and whether this is enough support to maintain or increase the Nation's competitive position in the development and production of technological products, vis-à-vis Europe and Japan, is problematical. The Nation will retain its position as a techno-economic world leader only so long as it maintains its technological capabilities. It likely will maintain those capabilities only so long as it maintains its position in basic scientific research. The old saw that begins "For want of a nail . . ." is applicable here.

Decisions made today about educational programs in science and

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[3] Drucker, Peter F. The Executive. London, Heinemann, 1966: 4.

[4] National Science Foundation. National Patterns of R. & D. Resources 1953—1978–79. NSF 78–313. Washington, U.S. Government Printing Office, 1978: 7

technology in high schools, universities, and colleges; about basic research facilities; and about scientific programs in basic research will impact upon the Nation's economic strength in the 21ts century. For example, today's support or non-support of education and basic research programs in fossil fuels, solar energy, the nuclear breeder reactor, and nuclear fusion energy will determine in large measure whether the United States, France, Germany, the U.S.S.R. or some other nation will be dominant in energy resources in the 21th century. It is likely that whichever nation or group of nations is dominant in energy at that time also will be dominant economically and militarily.

Of primary concern to the vitality of basic research conducted in universities and colleges and the Federal Government mission agencies will be the issue of adequacy of funding. Existing limitations on the funding levels of long-range basic scientific research programs and, more importantly, the unpredictability of funding (due to legislative appropriations made on a year-by-year basis) have caused and will continue to cause great concern among the Nation's basic research scientists. Their views are that a more assured continuity of funding will contribute to more effective overall conduct of basic research.

During the 1950's and 1960's, it was often stated that World War III was being fought in the laboratories of the United States and the Soviet Union. In much the same way today, the struggle for techno-economic leadership of the world in the late 20th and early 21st centuries will be determined to a significant extent in the educational establishments and basic scientific research laboratories of the United States, Europe, Japan, and the U.S.S.R.

Perhaps the Nation's political and social decisionmakers will determine that other societal priorities take precedence over competitive techno-economic priorities. That would be a valid society decision, however, but a downgrading of support for scientific and technological education and basic scientific research, for whatever reason, could contribute to a loss of the Nation's techno-economic leadership in the future.

2. UNIVERSITY RESEARCH

Many of the problems and opportunities associated with university research are also those associated with basic research, discussed above, since over 50 percent of the Nation's basic research is performed by universities and colleges. Over 85 percent of all Federal research funds, however, go to fewer than 100 of the Nation's approximately 3,000 universities and colleges. This apparent distortion in Federal funding patterns for university research reflects the "elite" status of some universities and colleges in scientific areas and may, in itself, be an unhealthy national situation.

From 1967 to 1978, about one-half of all Federal obligations for basic research went to universities and colleges, accounting for about two-thirds of their total financial support for basic research. University research is, and will continue to be, critical to basic research. The Federal Government likely will remain the major source of financial support for university basic research.

Unfortunately universities, and hence university research, appear to be entering a period of increasing problems associated with a complex of factors. Such factors include:

Constraints on scientific manpower, including decreases in student enrollments and the aging of the existing scientific manpower at universities, with a concomitant decline in the number of research opportunities for younger scientists;

Constraints on governmental financial support; associated with

Increasing governmental interference in university administration and affairs; and

A deterioration of scientific instrumentation and facilities.

The Nation's universities and colleges are still preeminent in the world's scientific establishment as evidenced by the number of their scientists who are recipients of Nobel Prizes. Yet, as noted above, there are signs of deterioration. Such warning signs suggest that the contributions of universities to the Nation's basic research capability could be adversely affected in the future.

3. FEDERAL GOVERNMENT SUPPORT OF R&D

The Federal Government provides over one-half of the funds for the Nation's total R&D effort, although it performs only about 15 percent of that work in its own facilities. Most of the rest of the Nation's R&D effort is performed by industry, with another approximately 15 percent performed by universities, colleges, Federally Funded Research and Development Centers (FFRDC's), and other nonprofit institutions.

The Federal Government's total R&D effort is carried out (performed intramurally or supported under contracts or grants) by its mission agencies, like the Departments of Defense and Energy, and by the National Science Foundation. The approximately $27 billion for the conduct of R&D for fiscal year 1979 is apportioned among the Federal Government's departments and agencies in the following way:

	Percent
DOD	45.8
DOE	15.5
NASA	15.2
HEW	11.6
NSF	2.8
USDA	2.2
EPA	1.3
DOT	1.2
Interior	1.3
Commerce	1.1
Subtotal	98.0

	Percent
Nuclear Regulatory Commission	(1)
VA	(1)
AID	(1)
HUD	(1)
TVA	(1)
Justice	(1)
Labor	(1)
Smithsonian	(1)
All Others	(1)
Total	100

1 Less than one percent.

As can be seen from the above table, Federal R&D is heavily oriented toward defense, energy, space, and health, which account for about 88 percent of total Federal R&D funds. The support of (largely) basic research by the National Science Foundation accounts for about three percent. A fundamental concern that continuously occurs in discussions of national science and technology policy is the relatively small amounts of Federal R&D funding for such civilian needs as housing, transportation, commerce, and the general advancement of knowledge in many areas. By contrast, high growth countries like Japan and West Germany devote relatively high proportions of governmental R&D budgets to civilian R&D uses. Japan, for example, devotes over 20 percent of its governmental R&D expenditures to economic development and about 55 percent to the advancement of knowledge. West Germany devotes about 50 percent of its governmental R&D expenditures to the latter category. The United States expends less than 10 percent of its governmental R&D budget in each of these areas.[5] By being the West's military arsenal, the United States may be weakening its R&D vis-a-vis the very countries which it is protecting with its military arsenal. The dilemma of choosing between (1) continuing this way, (2) abandoning the military arsenal stance, and/or (3) encouraging Japan and West Germany to become heavily involved in military R&D and to deemphasize their civilian R&D, is apparent.

Another aspect of Federal Government R&D that will continue to be of concern in the future is the impact which the Mansfield Amendment is having on scientific research. The Mansfield Amendment[6] and its subsequent modification,[7] were added to military procurement authorization acts in 1969 and 1970 to require that all research supported by the Department be mission oriented. Thus, some fruitful lines of research which might otherwise have been pursued, even though not directly mission oriented, may have been prohibited. While the Mansfield Amendment (original and its modifications) applied only to the Department of Defense for fiscal years 1969 and 1970, it has apparently impacted on other mission agencies as well and has had a continuing effect. This apparent constraint on scientific research could be investigated to determine whether its overall impact has been positive or negative on the Nation's total R&D effort.

Other aspects of Federal Government support of R&D are the role of the national laboratories, the Federal R&D Budget, and national science and technology policy and management, discussed below in Subsection 5 of this Section and in Subsections 2 and 4 of Section E of this chapter.

4. APPLIED RESEARCH AND INDUSTRIAL R&D

Although the terms "basic research," as discussed above, and "applied research" are not precisely defined in practice, essentially applied research is research "directed toward practical application of knowledge."[8] The related term "development" is generally taken to mean the

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[5] National Science Board. Science Indicators 1978. Washington, U.S. Government Printing Office, 1979: 146–147.
[6] Public Law 91–121, section 203.
[7] Public Law 91–441, section 204.
[8] National Science Foundation. National Patterns of R. & D. Resources 1953–77. NSF 77–310. Washington, U.S. Government Printing Office, 1977: 19.

use of "available information in the construction of a piece of operating hardware or a useful process, physical or social." [9] Together, applied research and development represent the reduction of knowledge (represented by basic research) to practical application.

About 23 percent of the Nation's total R&D effort is applied research and another 64 percent is development. The remainder, 13 percent, is basic research.[10] Although over one-half of the Nation's total R&D effort is funded by the Federal Government, about 71 percent is performed in industrial laboratories or in Government-owned but contractor-operated laboratories, such as the eight major multiprogram laboratories of the Department of Energy. The principal exceptions to this pattern are the R&D laboratories of the Federal Government's mission agencies which are staffed with U.S. Government personnel, like most Department of Defense laboratories and NASA's Lewis Research Center and Goddard Space Flight Center.

Most of the applied research and development laboratories servicing Federal programs (whether Federal in-house or industrial laboratories) have the Federal Government as the major sponsor and major procurer of services and products. This is particularly true of the defense and space R&D program efforts. The vitality of these laboratories and the applied research and development programs carried out by them will directly relate to government needs as expressed in real terms by R&D funding levels. Because such Federal programs are considered to be vital to the Nation, Federal support of industrial R&D for these purposes is strong and the related industrial R&D capabilities are also generally strong.

Another major aspect of industrial R&D is the approximately 65 percent which industry funds itself. In this aspect, industrial R&D is a cost of doing business and is only one of several investment alternatives available to businesses. In addition, the requirements for short-range profitability sometimes may cut into a company's long-range needs for R&D, particularly in smaller firms. Thus, it is possible that difficult economic circumstances will curtail industrial support of R&D in the future.

These is increasing evidence, largely offered through statements of industry representatives, that industrial R&D is beginning to deteriorate due in part to existing policies of the U.S. Government, like tax, antitrust, and regulatory policies, all discussed below in Section E. Of particular importance today is the overarching issue of industrial innovation which is affected by such things as governmental regulatory and financial policies, but which also goes to the heart of scientific and technical ingenuity and inventiveness. Some indicators of industrial innovation (like the numbers of U.S. patents granted to U.S. versus foregin citizens) indicate that U.S. industrial R&D and innovation is deteriorating vis-á-vis that of the other industrialized nations. Innovation is discussed below in Section D.

Just what is happening today in industrial R&D is difficult to determine with precision.

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[9] U.S. Congress. House. Committee on Science and Technology. Subcommittee on Science, Research, and Technology. Science Policy: A Working Glossary [Fourth Edition—1978]. Committee Print, 95th Congress, 2d session. Washington, U.S. Government Printing Office, 1978: 20.

[10] National Science Foundation. National Patterns of R. & D. Resources 1953—1978–79. NSF 78–313. Washington, U.S. Government Printing Office, 1978: vi.

> Research and development in American industry as an object of inquiry is more diffuse and harder to grasp than R&D in the Federal Government. In federal R&D, we have . . . some pretty good handles [on information about R&D].
>
> In industry R&D, on the other hand, thousands of separate companies are involved, each with its own interests, objectives, and ways of doing business. The variety and size of the total effort is more bewildering than in the Federal Government. . . . R&D in industry is more difficult to study than R&D in government, and the tools to study it are weaker.[11]

And yet from the total national policy viewpoint, industrial R&D probably will remain more important than R&D in the Federal Government with regard to the Nation's basic economic strength and the internal dynamics of the capitalistic system. Perhaps nothing will be more important to the continuing strength of the Nation's techno-economic system, aside from scientific and technological education as discussed in Section B above, than a comprehensive and in-depth understanding and modification of Federal policies to stimulate industrial R&D and innovation (see Section D, below).

5. NATIONAL LABORATORIES

National laboratories are only a part of the Nation's governmental and industrial R&D complex, but they are an important and valuable part. National laboratories like Argonne National Laboratory and Oak Ridge National Laboratory of the Department of Energy, Jet Propulsion Laboratory and Lewis Research Center of NASA, and the National Institutes of Health of the Department of Health, Education and Welfare, are R&D institutions of international repute. These laboratories are doing essential work for the Nation and its citizens. In some ways, however, these very productive capabilities possibly are not being used to their fullest potential. Some inefficiencies may be inevitable in large complex R&D systems and there may be some room for improvement in the management of these national laboratories. For example, the Department of Energy has 41 R&D facilities, uses several associated NASA laboratories, and has a number of production plants and other operations. It is recognized that this complex R&D organization is still evolving from the, originally, military nuclear R&D programs of the Manhattan Project and the Atomic Energy Commission to today's diversified energy program laboratories of DOE. Much still remains to be done, however to make these and other Federal laboratories more responsive in meeting the Nation's overall R&D goals, as well as the specific policies and program objectives of the individual mission agencies of the Federal Government.[12]

A possible approach to optimizing the R&D, and programmatic effectiveness of national laboratories in the future may be a comprehensive investigation of their total capabilities and potential followed by the design and establishment of an effective Federal laboratory coordinating-management structure. The Federal Laboratory Consortium currently is the only operating Federal organization with

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[11] Shapley, Willis H. and Don I. Phillips. Research & Development, AAAS Report III: R&D, in the Federal Budget: Fiscal year 1979, R&D, Industry, and the Economy. Washington, The American Association for the Advancement of Science, 1978: 53.

[12] See U.S. Congress. House. Committee on Science and Technology. Subcommittee on Advanced Energy Technologies and Energy Conservation Research, Development, and Demonstration. The Role of the National Energy Laboratories in ERDA and Department of Energy Operations: Retrospect and Prospect. Committee Print, 95th Congress, 2d session, Washington, U.S. Government Printing Office, 1978, 523 p. See especially therein Appendix V: Albert H. Teich. Bureaucracy and Politics in Big Science: Relations Between Headquarters and the National Laboratories in AEC and ERDA.

responsibility for Federal laboratory coordination, but cooperation is on a voluntary basis and is only for technology transfer and technical assistance to States and industry. The Consortium was not designed to be a full-fledged laboratory coordinating and management structure of the order suggested here. There have been proposals in the past to establish a "Federal laboratory administration" to administer some aspects of the operations of the national laboratories while permitting many existing programmatic relationships with the Federal mission agencies to continue. While such proposals have not received widespread support in the S&T community, they are least represent one potential approach to optimizing the effectiveness of national laboratories in more broadly supporting national goals.

6. INTERNATIONAL SCIENCE AND TECHNOLOGY

"International science and technology" is a rubric that has many aspects, from scientific and technological cooperation with the Soviet Union to the international implications of appropriate technology (the "small is beautiful" concept championed by E. F. Schumacher [13] and others). "International science and technology" also includes international techno-economic competition in high-technology products (discussed below in Section D), international trade in high-technology armaments, international technology transfer to the developing nations to the Third World, the scientific and techlonogical activities of the United Nations and other international organizations, like the upcoming U.N. Conference on Science, Technology, and Development, and many other activities and relationships.

In most cases, international science and technology is a dimension of other scientific and technological activities discussed elsewhere in this analysis. In some cases, however, aspects of international science and technology can be dealt with most fruitfully under that term itself. For example, the recent refusal of the Federal Government to grant export licenses for U.S. firms to sell some high-technology products (computer systems) to the Soviet Union is a case of the use (or nonuse) of science and technology to further U.S. international policy objectives. The U.S. policy objectives in that case interfered with the commercial objectives of the U.S. firms involved. In other recent instances, however, U.S. international science and technology policy objectives have furthered domestic commercial objectives, as in the case of U.S. firms opening discussions (1) to sell a telecommunications Earth satellite to the Peoples Republic of China, and (2) for commercial development of petroleum resources in the Peoples Republic of China.

The issue of international technology transfer will be a particularly thorny issue. Many representatives of U.S. industry hold that it is in the best interests of the United States both to sell high technology products abroad and to license foreign companies to produce U.S.-developed high technology products for appropriate fees and royalties. Opponents of this view hold that foreign companies are likely to take such U.S.-developed technologies, improve upon them, and sell

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[13] Schumacher, E. F. Small Is Beautiful: Economics as if People Mattered. New York, Harper and Row, 1973, 290 p.

the improved products back to U.S. consumers. In addition to this factor, many representatives of U.S. labor unions hold that licensing U.S. technology abroad is in effect exporting jobs abroad—jobs that would otherwise be done in the United States by U.S. workers.

On the other side of this argument is the fact that about 50 to 60 percent of the world's R&D is performed outside the United States. It is reasonable to assume, therefore, that U.S. industry may have more to gain from a fairly free international flow of technology than it has to lose. Moreover, there is the pervasive and persuasive argument that if the United States does not license its production technologies and techniques to other countries, some other nation—like Japan or Germany—soon will. This seems to be occurring now, for example, in the case of nuclear power plant development following the Carter administration's restrictions on the transfer of some sensitive nuclear reactor technologies abroad under provisions of the Nuclear Non-Proliferation Act of 1978.[14]

What is certain is that the issue of international technology transfer is quite complex, involving as it does both short-term and long-term aspects of business profitability, national industrial viability, and international relations. The basic issues seem to be: Will the United States, overall and over time, benefit from international technology transfer or will it not? should the United States have different policies for developed and developing nations? and should, the international aspects of U.S. science, technology, and techno-economics be reevaluated in light of the possible clash between evolving international techno-economic competitiveness and the Nation's historical commitment to free trade?

In economic terms, U.S. scientific and technological capabilities will be used by the U.S. Government either as a carrot or as a stick in international relations. The potential for the U.S. science and technology establishment to serve the ends of U.S. international policy is significant and, in the future, is likely to continue to enhance the symbiosis between U.S. industry and the U.S. Government.

7. SCIENTIFIC AND TECHNICAL INFORMATION

In a sense, everyone knows what scientific information (STI) is—data, reports, analyses, computer-assisted services, and so on. In another sense, STI as a practical concept is quite diffuse and has not been reduced in practice to a generally acceptable and comprehensive system. The need for such an adequate STI system continues to increase as the Nation's R&D, social, and economic problems continue to grow.

A recent Arthur D. Little, Inc., report prepared for the National Science Foundation characterizes the evolution of the national STI environment and suggests corresponding actions required to develop a national STI system. The following table from that report indicates future national STI needs in broad terms.[15]

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[14] Public Law 95–242, see especially section 302.

[15] Arthur D. Little, Inc. Passing the Threshold Into the Information Age—Perspective for Federal Action on Information. A Report to the National Science Foundation. Volume I. Cambridge, Mass., Arthur D. Little, Inc., 1978 : 10.

THE THREE INFORMATION CONTEXTS AND ERAS

	Time Scale of Recent Emphasis	Basic Use of Knowledge	Corresponding Information System
Discipline-based	Era I Traditional, from 19th Century and continuing	Study and development of scientific disciplines; strong growth of knowledge motivation	Discipline-based information systems; mainly research libraries and journal complexes
Mission-based	Era II WW II with height in the 1960's and continuing	Big science & technology; emphasis on Missions like: "Build an Atom Bomb"; "Put a Man on the Moon"; strong engineering and application emphasis	Mission-based information systems; large government-operated documentation systems, computer-assisted
Problem-based	Era III Some starts in the late 1960's; growing emphasis in 1970's	Emphasis on solving socio-technical systems problems; examples; providing better housing and transportation; improving quality of life in cities; equalizing job opportunities; preserving the environment; etc.; strong value judgment inputs.	Problem-based information systems (forms are still being determined)

Each Era represents a value system, a context of activities and a set of corresponding goals and objectives (which may be more or less explicitly articulated).

STI is an area of science and technology policy and practice that currently may not be receiving adequate attention from policymakers. Because of the comprehensive nature of a systematic approach to STI, strong Federal Government leadership will be required for its formulation and implementation. For example, a recent congressional publication states that:

Congressional action is needed. Numerous studies over the past 20 years point to deficiencies in existing programs and the lack of policy guidance, and portend future problems. The executive branch has yet to assume full responsibility for the development of STI as a national resource. Congress has the opportunity to be the catalyst for achieving constructive change.[16]

The world abounds in raw science and technology information and the supply is likely to increase dramatically in the years ahead. It will take concerted efforts on the part of Government policymakers to develop a truly optimal information system that will support science and technology without waste of information or loss of communications effectiveness.

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[16] U.S. Congress. House. Committee on Science and Technology. Subcommittee on Science, Research, and Technology. Optimizing the Value of U.S. Scientific and Technical Information: Legislative Options. October 1978: 20.

D. Techno-Economic Factors

Many factors involved in science and technology are strictly scientific and technological in a narrow sense, such as basic scientific research, or strictly economic in a narrow sense, like investment tax credits. It is useful, however, to consider a wide area of governmental and private productive activity as being "techno-economic" in nature because of the significant technological and economic symbosis involved and because of the close interrelationships between R&D and economics which exist in practice. An excellent example of techno-economic activity is industrial innovation, discussed immediately below. Industrial innovation may be defined as the process connecting scientific and technological R&D to commercial and economic activity. Other definitions describe industrial innovation more broadly and subsume R&D within it. However it is defined, industrial innovation will continue to be a major techno-economic process in industrialized nations.

The techno-economic process is not merely an interface between largely scientific and technological activities and largely economic activities; rather it is a process continuum or spectrum of activities from basic scientific research to the marketing of products and services. In this sense, science and technology will contribute significantly to total national economic activity. A Brookings study [17] attributes up to one-third of the economic growth in the United States from 1929 to 1969 to advances in technological, managerial, and organizational knowledge. This technological factor has accounted for more economic growth than any of the other factors analyzed in the study which, in decreasing order of effect on economic growth, were: "labor, except education," "capital," "economies of scale," "education," and "resource allocation." Without attempting to carry that analysis further, it appears clear that techno-economic processes will be basic to the Nation's overall economic strength and growth in the future.

1. INDUSTRIAL INNOVATION

Innovation is a (largely) industrial process whereby ideas or inventions are reduced to practical application and profitability through the marketplace in the form of new or improved products, processes, or services. Although R&D is an important part of industrial innovation, many other nonscientific and nontechnological factors enter into the process. While innovation is largely an industrial process it has, particularly since the World War II period, relied heavily upon the U.S. Government for support in the form of the provision of basic research, financial assistance, Government procurement, and similar incentives and practices.

There is currently a widespread concern in industry, academia, Government, and the Nation's R&D establishment generally that industrial technological innovation in the United States is declining both absolutely and in relation to that of other industrialized countries. The situation is not completely clear, however, since there are

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[17] Denison, Edward F. Accounting for U.S. Economic Growth 1929–69. Washington, The Brookings Institution, 1974: 129–131.

few statistics to support this belief unequivocably. The statistics most often cited in discussions of technological innovation are statistics referring to decreases in Federal R&D funding support. Such statistics are "input" statistics rather than "output" statistics: they measure what is believed to contribute to innovation rather than being measures of innovation themselves. Some measures of industrial innovation "out put" such as: (1) the number of U.S. patents granted per year to U.S. citizens vis-à-vis foreign citizens, (2) measures of industrial productivity (see subsection 3, below), and (3) measures of the U.S. competitive position in U.S. international high-technology trade (see subsection 5, below) also suggest a significant deterioration in U.S. industrial innovation over the last decade.[18] Not everyone, however, interprets such data in the same way. For example, in the first annual Science and Technology Report to the Congress prepared by the National Science Foundation, it is stated that:

> Data on technological output (e.g., patenting, licensing, and international earnings from R&D intensive activities) are inadequate to enable us to make unqualified claims regarding U.S. technological capabilities. Based on the data we do have, it seems fair to say that there has been little or no erosion in U.S. technological capabilities. Neither the available economic nor technical indicators provide hard evidence of an eroding U.S. technical position which can be tied to negative economic consequences.[19]

In addition to such statistical evidence, the accumulating experimental evidence of Government and industrial representatives that U.S. technological innovation is deteriorating has been given considerable weight in recent forums at which U.S. R&D and industrial innovation have been discussed.[20]

The apparently deteriorating U.S. position in technological innovation is often attributed to a number of factors such as the following:

A decline in R&D spending, particularly by the Federal Government. Industrial R&D expenditures have remained relatively constant as a percentage of U.S. gross national product over the last ten years or so. Over the same period, however, Federal priorities have shifted toward civilian R&D but increases in Federal funding for civilian R&D have not matched the large decreases in Federal funding for defense and space R&D.

An increase in national economic uncertainty characterized by inflation, high interest rates, high taxes, difficulties of R&D firms (particularly small R&D firms) in obtaining venture capital, and so on.

An increase in business uncertainty related to governmental regulatory activities, particularly those of the Federal Government, the related additional costs of doing business, and the "defensive R&D" required to satisfy many governmental health, safety, and environmental regulations (discussed in section E of this chapter, below).

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[18] See, for example, National Science Board. Science Indicators 1978. Washington, U.S. Government Printing Office, 1979. p. 263.

[19] U.S. Congress. House. Committee on Science and Technology. Science and Technology Report 1978: First Annual Report to the Congress Submitted in Accordance with the National Science and Technology Policy, Organization and Priorities Act of 1976. Committee Print, 95th Congress, 2d session. Washington, U.S. Government Printing Office, 1978: xii.

[20] See Phillips, Don I., Patricia S. Curlin, and Ralph L. Petrilli, eds. R&D in the Federal Budget: R&D, Industry, and the Economy (Colloquium Proceedings). Washington, American Association for the Advancement of Science, September 1978. 175 p.

The stifling effects of some Federal policies directly affecting industrial innovation, like U.S. Government patent policy involving the ownership of inventions resulting from federally-funded R&D, and Federal antitrust policy.

An apparently decreasing propensity of business to take risks.

Due to the above factors, a resulting shift in apparent industrial commitment from long-range fundamental innovation to short-range, low-risk, incremental changes designed for short-term profitability. This trend is likely to have serious long-term impacts on U.S. economic growth and strength vis-à-vis other industrial nations.

It is apparent from the nature of the above factors that at least two types of cyclical phenomena are occurring in industrial innovation simultaneously. First, the possible deterioration in industrial innovation tends to feed on itself. For example, a worsening economic situation causes reduced Federal and private financial support for R&D than would otherwise be the case. Concurrently increasing governmental regulation also may contribute to less practical and long-range R&D, all of which leads to a decrease in innovation and a related long-term lessening of industrial profitability, and so on to another deteriorated cycle. Second, the cycle is very much a techno-economic cycle: R&D and innovation directly affect economic change (through the provision of technological products and processes) which together with governmental regulation impact directly back on R&D innovation.

Industrial technological innocation is an integral part of the techno-economic process that powers the Nation's economy. Currently there is evidence that the process is less effcient (1) than it was in the recent past, and (2) in relation to other industrialized nations. Because industrial innovation is a complex techno-economic process, improvements in innovation will require improvements in both sicentific and technological conditions and economic conditions, probably simultaneously in most cases.[21]

Industrial innovation is currently the subject of a major Administration study being prepared in the form of a Presidential Review Memorandum by a large interagency group under the direction of Dr. Jordan Baruch, the Assistant Secretary of Commerce for Science and Technology. The results of that study are due by about mid-1979.

In summary, scientific and technological processes, particularly as they contribute to the Nation's economic process, are not independent of that economic process. It appears that just when science and technology may be needed most to stimulate the Nation's techno-economic health and growth, their effectiveness may be constrained by economic and business (including regulatory) conditions. The situation appears to be much like the relationship between human health and human work. If a person is wealthy enough he can afford medical care whether he works or not. If he must work to support himself, however, an illness can prevent him from earning enough money for medical care. As he becomes sicker, he also becomes less able to provide for medical

[21] See, for example, Mogee, Mary Ellen. Industrial Innovation and Its Relation to the U.S. Domestic Economy and International Trade Competitiveness. CRS Report No. 78-204 SPR. Washington, Library of Congress, Congressional Research Service, October 13, 1978. 61 p.

care—a technological shot in the area. While this analogy is very rough, it probably is true that the United States may no longer be rich enough, if it ever was, to allow itself to become unhealthy in the techno-economic sense because the Nation has no technological physician or rich economic uncle who will help it.

2. COMMERCIALIZATION

"Commercialization" is a process related to industrial innovation that is receiving increased governmental attention, particularly since the establishment of ERDA in 1975. ERDA was, and the Department of Energy now is, engaged in assisting industrial firms in making the transition from research, development, and demonstration projects, which are largely supported by the Federal Government, to commercially viable energy-related projects to be supported by the industrial firms themselves. This is basically a technology transfer process which may have a potential for wide application throughout the Government-industry R&D complex.

Commercialization as practiced by ERDA and the Department of Energy is largely unique to those organizations. ERDA had, and now DOE has, a legislative mandate to foster commercial sustainable, energy-related programs. Much may be learned from investigating the ERDA and DOE experiences and similar technology transfer experiences of NASA, the Department of Defense, the Small Business Administration, and other governmental agencies. There may be many potentially economically productive activities nascent in Government R&D programs which (1) the Federal Government cannot legitimately undertake because the business of Government is not business, and (2) business will not undertake because (*a*) it cannot afford the innovation costs, or (*b*) it will not risk commercial production since it cannot, for example, obtain relevant patent rights, or (*c*) it cannot obtain, in practical terms, the techno-economic information and "hands-on" experience required to transform a Government-run R&D program into a privately-run, profit-making, commercial activity, or (*d*) markets have not yet been identified, aggregated, or developed.

A significant part of the commercial potential of the Nation's federally funded R&D may be going to waste today because of a practical hiatus—examples of which are given in the preceding paragraph—between Government programs and private profit-making realities. Commercialization processes, involving Government and industry jointly, may be widely useful in bridging what may be a wasteful gap in Government-industry techno-economic processes. If the commercialization experiences of ERDA and the Department of Energy and other Government agencies have the potential for being useful more generally, such processes should be investigated and adapted to the R&D program of other major Federal mission agencies.

3. INDUSTRIAL PRODUCTIVITY

Industrial productivity is a measure of industrial economic effectiveness, defined generally as economic output (economic product, such as gross national product, with modifications) divided by economic input (man-hours of labor). Historically, U.S. industrial productivity has been higher than industrial productivity in other industrialized nations. That situation continues today even though the U.S. rate of increase of productivity, in many industries has fallen significantly and is now below the rates of increase of productivity of other nations, particularly European countries and Japan. This situation may be a natural and not unhealthy reflection of the maturation of U.S. industry and the continued rapid development of the younger (rebuilt) industries of Japan and Europe which were destroyed during World War II. Many persons, however, are concerned today with what looks like a weakening of U.S. industry, and many statistics of the relative growth rates of national industrial productivity support such concerns.

Another reason that industrial productivity is of concern is that it is closely related to industrial innovation which seems to many observers to be deteriorating in the United States (discussed above in subsection 1). Industrial innovation and productivity are related in the sense that:

> Without innovation, productivity growth cannot occur; without productivity growth, the capital necessary to spur innovation will not exist. And without both innovation and productivity increases, . . . the very quality of our lives must decline.[22]

For approximately two-thirds of the 62 major U.S. industries for which the Bureau of Labor Statistics of the U.S. Department of Labor reports data, industrial productivity growth rates for the past decade have been significantly lower than at any other time since World War II. In addition to this general situation, some specific situations are causing national concern. Most notably, the European and Japanese steel industries have improved their productivity to several times that of the U.S. steel industry and are causing the U.S. steel industry serious competitive problems.

While it is currently unclear whether the decreasing growth rate of U.S. industrial productivity is itself a deleterious condition, it is an indication of significant industrial change. Such change may be relevant in assessing the Nation's future scientific and technological capabilities since it is generally accepted that technological innovation is the single most important factor affecting industrial productivity, typically accounting for about one-half of productivity gains. Education, capital, economies of scale, and resource allocation factors account for the remainder of the gains in productivity in roughly equal proportions. Deteriorating U.S. innovation may have caused, in large part, the decreasing growth rates in U.S. industrial productivity over the last decade. As indicated above, another unfavorable techno-economic cycle, this one involving industrial innovation and productivity, may be affecting both the technological strength and economic viability of the Nation. Such evidence indicates that a comprehensive techno-economic solution will be required for the problems involved in economic change.

4. SMALL BUSINESS

Small firms which perform R&D, innovate, and produce high technology products may contribute to the techno-economic processes and

[22] Productivity [whole issue]. I.E.E.E. Spectrum, v. 15, October 1978: 34. Also see Mansfield, Edwin. The Economics of Technological Change. New York, W. W. Norton and Company, Inc., 1968, especially Chapter 2, "Technological Change and Productivity Growth,": 10–42.

health of the Nation out of all proportion to their individual sizes and number. Many small high-technology firms do use R&D funds more efficiently than larger firms and have been responsible for a large number of major technological innovations. The so-called "Route 128 phenomenon" around Cambridge, Massachusetts, in the 1960's was characterized by many small, highly innovative, high-technology firms contributing to the Nation's space and defense programs.

Based upon this and similar experiences, it would seem to be in the best interests of the United States to have as many small high-technology firms as possible stimulating and contributing to R&D and innovation in the Nation's industrial R&D establishment. Currently, however, many small high-technology firms seem to be undergoing operating difficulties because of problems related to the national economic situation. Many smaller firms do not have the financial depth to ride out difficult economic times, as do larger firms. Another problem of particular concern to smaller high-technology firms today is the difficulty in responding to government reporting and regulatory requirements; small firms may not have the financial strength to hire specific, "non-productive" employees to handle government reporting and regulatory requirements, whereas these burdens represent a relatively smaller proportion of the business overhead costs of larger fims.

Conditions such as these seem to be stifling some small, high-technology firms and even may be preventing the establishment of new firms. For example, the number of successful public stock offerings for small high-technology firms in the United States fell from 200 per year in 1969 to zero in 1975. During approximately this same period, indicators of the health of the Nation's R&D capability and indicators of industrial innovation also began to decline. While many other factors contribute to the health of R&D and innovation, the existence of a body of small high-technology firms would seem to be—based upon U.S. experience—quite important to the overall health of the Nation's R&D and industrial innovation capabilities. Because many such firms are now experiencing difficulties operating or coming into existence, special governmental concern with the problems of the small high-technology firm would seem to be required to ensure that this potentially rich source of R&D and innovation is not lost because of problems which may be relatively easily rectified by the Federal Government, particularly in those cases where the Federal Government may be a major problem itself as in the regulatory and paperwork problem area.

5. INTERNATIONAL TECHNO-ECONOMIC COMPETITION

International techno-economic competition has several sides:

Until after World War II, the United States had a favorable balance of international trade because it was a major exporter of natural resources and manufactured goods, and required relatively few imports. Also, immediately after World War II, the industrial sectors of Japan and Europe were being rebuilt.

This situation has now changed with imports of natural resources, particularly petroleum, and manufactured products, especially consumer goods such as electronic products and automobiles from Japan and Europe, contributing to an overall unfavorable balance of international trade.

The favorable components of the Nation's otherwise unfavorable balance of international trade are provided by exports of agricultural products and high-technology products, like computers and airplanes. Indeed, agricultural products may be considered to be the results of very successful research and development in agriculture by the Nation's agricultural schools, the U.S. Department of Agriculture's research and extension services, and U.S. farmers themselves.

The Nation's international position regarding high-technology products (mainly the non-agricultural products) has also changed over the last decade. A major and increasingly critical factor in the U.S. economy will be the decreasing international competitiveness of U.S. high-technology exports vis-à-vis Japanese and European high-technology products, and the increasing penetration of the U.S. domestic market by these foreign producers. Historically, the United States has had few effective competitors for products like computers and commercial airliners. Now, however, Japan is getting into the computer market aggressively, and Europe is competing strongly with the Concorde and the newer European-made airbus. Consequently, these products could go the way of television receivers, whose production now is dominated by the Japanese. Although currently the unfavorable U.S. balance of international trade is due mainly to petroleum imports, the future of U.S. international trade is worrisome with these Japanese and European inroads into high-technology export products.

There are opposing views within the United States as to whether the U.S. export of high-technology "know-how," rather than merely the export of high-technology products, is detrimental to the U.S. techno-economic position over the long term.

Many U.S. industrial firms engage in "export of technology," the licensing of production technologies and techniques and other transfers of technological "know-how" to foreign companies. Some observers believe that this type of industrial activity will boomerang in the future because foreign companies will take U.S.-developed technological know-how, use it as a base for further foreign innovation, and out-compete U.S. firms trying to sell the same types of high-technology products. Even without this type of a situation occurring, however, some U.S. labor union representatives claim that the export of U.S. technology to foreign firms is really an export of U.S. jobs abroad since foreign workers, rather than U.S. workers, manufacture the products.

As in the other techno-economic factors discussed above, there are indicators that U.S. trade in high-technology products and processes is deteriorating. While the total U.S. high-technology industry is probably sound, a few U.S. industries are in a vulnerable position, for example, the steel industry, the electronics and television receiver industries, and conceivably even the commercial airliner manufacturing and/or computer industries. Many reasons have been given for the apparent loss of U.S. international high-technology competitiveness.

Perhaps two of the most important reasons are (1) the very high motivation to compete internationally, evidenced by the Japanese and western European high-technology firms, and (2) the relatively less mature and thus relatively faster growing economies of those countries. Whatever the reasons, U.S. high-technology firms will continue to be in a highly competitive race for international markets for high-technology products and processes while the U.S. domestic market will remain increasingly vulnerable to many high-technology imports.

E. Political and Governance Factors

Politics and governance form part of the ambience in which science and technology processes occur and represent part of the societal forces driving science and technology from the outside. In the complex technological society which is the United States, little will be done in the political and governmental areas which will not impact in some way on science and technology and, conversely, there probably are few areas in science and technology that will not affect politics and government in some way.

1. NATIONAL GOALS IN SCIENCE AND TECHNOLOGY

National goals of the United States have been articulated since the Declaration of Independence up to those in recent acts of Congress and presidential statements and documents. For the most part, articulated national goals reflect the consensus of American opinion on specific issues. Perhaps the most pertinent list of national goals relating to science, technology, and economic change are those incorporated into P.L. 94–282, the National Science and Technology Policy, Organization, and Priorities Act of 1976. These "priority goals" are as follows:

(1) Fostering leadership in the quest for international peace and progress toward human freedom, dignity, and well-being by enlarging the contributions of American scientists and engineers to the knowledge of man and his universe, by making discoveries of basic science widely available at home and abroad, and by utilizing technology in support of United States national and foreign policy goals;

(2) Increasing the efficient use of essential materials and products, and generally contributing to economic opportunity, stability, and appropriate growth;

(3) Assuring an adequate supply of food, materials, and energy for the Nation's needs;

(4) Contributing to the national security;

(5) Improving the quality of health care available to all residents of the United States;

(6) Preserving, fostering, and restoring a healthful and esthetic natural environment;

(7) Providing for the protection of the oceans and coastal zones, and the polar regions, and the efficient utilization of their resources;

(8) Strengthening the economy and promoting full employment through useful scientific and technological innovations;

(9) Increasing the quality of educational opportunities available to all residents of the United States;

(10) Promoting the conservation and efficient utilization of the Nation's natural and human resources;

(11) Improving the Nation's housing, transportation, and communication systems, and assuring the provision of effective public services throughout urban, suburban, and rural areas;

(12) Eliminating air and water pollution, and unnecessary, unhealthful, or ineffective drugs and food additives; and

(13) Advancing the exploration and peaceful uses of outer space.

Six of the 13 priority goals (numbers 2, 3, 7, 8, 10, 11) relate directly to science, technology, and economic change while seven (numbers 1, 4, 5, 6, 9, 12, 13) are apparently less directly related. Of the second group, it may be useful to consider number 4—contributing to national security—in a little more detail.

A comprehensive study on science, technology and American diplomacy recently prepared for the Congress [23] suggests the need for redefining "national security [to require] that cognizance be taken of such elements as:

(1) The assured flow of imported raw materials to mass-production, low-technology industries;

(2) The availability of a sound railroad system, without which the U.S. steel industry would close down in 10 days;

(3) The maintenance of the total flow of intelligence, including data from satellite overflights, to assure stability and reliable maintenance of the deterrent;

(4) The desirability of encouraging a consumer-oriented technological trend in the Soviet Union to reduce the Soviet resource allocation to arms development;

(5) The growing technological interdependence among nations spurred by such developments as the rapidly spreading multinational corporations and the growing need for global allocations of nonrenewable resources;

(6) The serious shortage of capital required for maintenance of the U.S. industrial plant, as well as for investment in innovation;

(7) The increasing vulnerability of U.S. industry, transport, communications, and other large services systems, to all kinds of disruptions as technology becomes more complex and units grow in size to exploit economies of scale;

(8) The serious threat of nuclear proliferation in the absence of adequate safeguards for nuclear fuel elements and fuel reprocessing facilities; and

(9) The value of the highly developed U.S. agricultural technology with its great political leverage in the developing and developed world."

Eight of these nine elements are directly techno-economic in nature while the other element (number 3, the maintenance of the total flow of intelligence) probably has some technological and economic aspects.

What these two recent lists of goals and subgoals suggest is that

[23] U.S. Congress. House. Committee on International Relations. Subcommittee on International Security and Scientific Affairs. Science, Technology, and Diplomacy in the Age of Interdependence. Committee Print, 94th Con., 2d sess. Washington, U.S. Govt. Print. Off., 1976. 492 pp. See especially pages 313 to 317.

the historical U.S. goal of national security perhaps should be redefined to emphasize, in light of changing international techno-economic conditions, the important techno-economic aspects of national security in addition to the more generally understood military security aspects. Perhaps it would be useful in these critical times of economic and military insecurity,[24] to begin to evolve a new articulated national goal of techno-economic security. The articulation of such a national goal would either reflect or crystallize a national consensus and awareness concerning the nature of existing and likely future international techno-economic realities. In 1946, the Full Employment Act reflected a then newly preceived national goal of full employment. In a similar fashion, if "techno-economic security" is now a useful and valid national goal, it too could be incorporated into national policy, including legislation. The suggestion here, however, is not that ambitious. It is merely to consider whether a national goal such as techno-economic security is ripe enough for articulation at the national level and, if so, how Federal policies could be developed around such a national goal. If international techno-economic competition is a major international battleground of the future, a redefinition of national security may be required.

2. FEDERAL SCIENCE AND TECHNOLOGY POLICY AND MANAGEMENT

Science and technology have internal dynamics of their own. Without limitations on resources, scientists could probably pursue interesting avenues of scientific research into the unknowns of nature forever without outside guidance. Likewise, engineers and businessmen probably also could continue to find new methods to reduce the fruits of science to practice in ways that would be profitable from a corporate financial viewpoint but not necessarily beneficial to society and/or the environment as a whole. In the same way that war is too important to be left to the generals, science and technology are too important to be left just to scientists, engineers, and businessmen.

Particularly since World War II, Federal policymakers have taken, of necessity, increasing responsibility for directing science and technology along the lines of preceived national interests. De facto policymaking occurs at all levels of the science and technology spectrum, but comprehensive and rationalized policymaking can only occur in the Federal system, at the congressional, presidential, or sometimes departmental or agency levels. Consequently, science and technology policy in this discussion refers generally to those aspects of policy formulation and implementation at the congressional, presidential, and sometimes lower levels which affect the practice of science and technology at the laboratory, corporate, or Federal departmental or agency level.

Under Public Law 94–282, the National Science and Technology Policy, Organization, and Priorities Act of 1976, the position of presidential science advisor and the Office of Science and Technology Policy (OSTP) were reestablished within the Executive Office of the President after that position and office were delegated to the Director

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[24] It is assumed here that parity of nuclear terror is not a particularly secure military position.

of the National Science Foundation by President Nixon in 1973. Also established under Public Law 94–282 was the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) which is charged with coordinating Federal R&D efforts in several areas. With these mechanisms the Congress hoped to improve the science and technology policymaking apparatus in the Federal Government and did so. There is probably considerable potential for strengthening the Federal science and technology policymaking structure. For example, two organizational extremes in the spectrum of high-level Federal science and technology policymaking would be (1) a Department of Science and (2) a Federal R&D coordinating mechanism.

The Department of Science concept has been considered by Congress on and off for many years but has not thus far been deemed an adequate response to the problems of national science and technology policymaking and management. On the other hand, existing high-level efforts at interagency cooperation in the areas of science and technology, as exemplified by FCCSET, may not be strong enough or effective enough to cope with future national problems and opportunities to which science and technology may be able to contribute.

Perhaps a middle ground for current congressional consideration would be what might be termed a "Federal science and technology policy and program coordination and management mechanism with teeth." Although the OSTP probably is advising the President in science and technology policy areas as well as any 24-person operation could, what is required for comprehensive "science and technology coordination and management" is probably a permanent operation of several hundred persons with cross-cutting authority to require science and technology-related actions throughout the operating levels of the Federal departments and agencies. While a cross-cutting operation currently may not be politically or even legally possible, such an operation, or something like it, may be required for the most effective formulation and implementation of science and technology policy in the future.

Further examination and evaluation of the Federal science and technology coordination and management function would seem to be required if U.S. science and technology policy is to be formulated and implemented on a comprehensive and rationalized basis. Although Public Law 94–282 is a significant step forward, many observers of science and technology policy believe that it cannot be the final step if Federal science and technology policymaking and management at the presidential level are to be effective enough to cope with perceived and unforeseen problems and opportunities requiring the application of the Nation's science and technology capabilities.

3. THE CONGRESSIONAL AUTHORIZATION PROCESS AND SCIENCE AND TECHNOLOGY POLICY

Most federally-funded R&D programs are authorized on an annual basis. Because of the nature of science and technology, however, a longer-term approach may be more appropriate for many R&D programs. Historically, funds for Federal activities and programs, including R&D programs, have been authorized and appropriated by the

Congress and budgeted by the executive branch on an annual basis. Although many Federal programs are funded by continuing authorizations, since the end of World War II there has been a trend to require annual authorizations for R&D programs starting with those of the Department of Defense, and continuing with those of NASA, the Department of Energy, and now most other major R&D programs. In the 95th Congress, for example, Public Law 95–322 was passed to require the authorization of appropriations for the National Bureau of Standards (NBS) for the first time. Moreover, the House of Representatives and the Senate expressed interest in requiring the authorization process for NBS to be for a two- or three-year period rather than annually. There also was interest in authorizing the appropriations of the National Science Foundation for a two-year period rather than for a one-year period as in the past.

Thus, concurrently with the trend to include most major R&D programs with a periodic authorization process, there is evidence that in some cases a more than one-year authorization period may be the most appropriate. Several things make federally funded R&D programs different from other Federal programs. In particular the difference is in the long term commitment of highly educated manpower and extremely complex and expensive equipment and facilities to carry out such programs. Without such long term continuity and commitment, many scientific and technological research, development, and demonstration programs may not be planned, administered, and evaluated as effectively as would otherwise be possible. While it has not yet been shown conclusively that multiple-year funding would contribute to a more efficient administration of major R&D programs, it may now be timely to examine this issue in depth. This is particularly so because in addition to the substantive factors mentioned above, increased efficiencies in the administration of federally funded R&D programs would to some extent offset the increased Federal budget constraints on R&D and the decreasing value of the R&D dollar because of inflation.

4. R&D FUNDING AND BUDGET

The Federal Government influences and directs the Nation's science and technology in many ways: through congressional foresight and oversight procedures, through the advisory function of the Office of Science and Technology Policy in the Executive Office of the President, and through legislative and executive statements of national goals and policies. In another sense—the bottom line is what type of R&D the Federal Government funds, and to what extent it funds it. In this sense, the Office of Management and Budget in the Executive Office of the President is a major Federal science and technology policymaker as are the authorizing, appropriations, and budget committees of the Congress.

The Federal Government affects the nature of national R&D by the way it apportions funds according to:

The other sources of R&D funds; these other sources being mainly industry, universities and colleges, and other nonprofit institutions;

Who performs the R&D: whether the Federal Government itself, or industry, universities and colleges, Federally Funded Research and Development Centers, or other nonprofit institutions;

The character of the R&D: whether is is basic research, applied research, or development; and

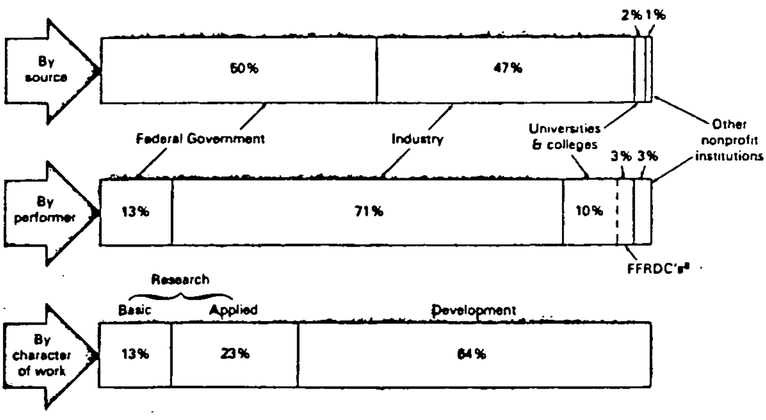
The Federal mission or mission agency supported.

The relationships between the first three factors are shown in the following chart. The R&D funding relationships between the Federal mission agencies were shown above in subsection C.3 of this chapter and are set forth again here in abbreviated form:

Mission agency:	*Fiscal year 1979 Federal R. & D. budget (percent)*
DOD	45.8
DOE	15.5
NASA	15.2
HEW	11.6
NSF	2.8
Subtotal	90.9

The national R&D effort

EXPENDITURES FOR R&D = $51.6 BILLION, 1979 (est.)



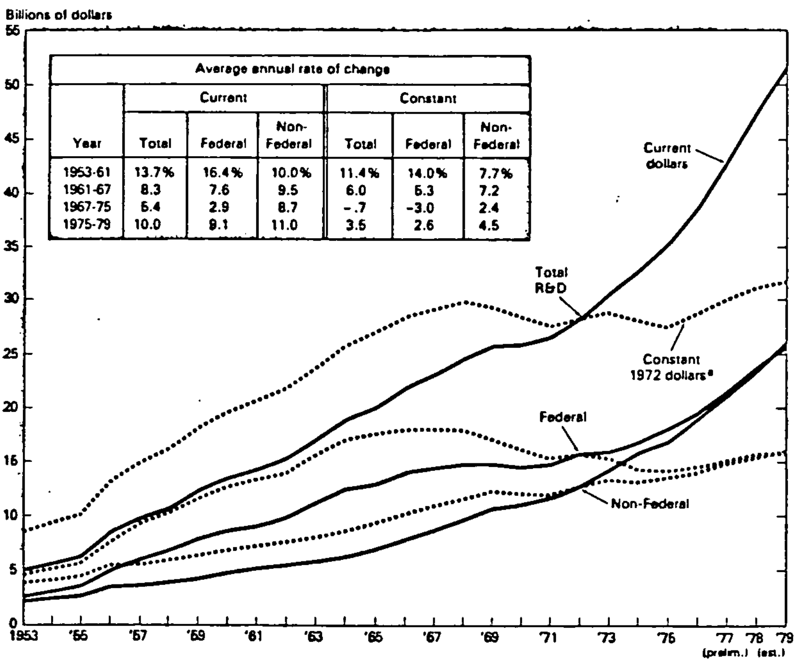
Source: National Science Foundation. National Patterns of R. & D. Resources: 1953—1978–79. NSF 78–313. Washington, U.S. Government Printing Office, 1977: vi.

Looking at how political and governance factors affect science and technology in the broad sense, it is clear that the Federal Government, through its purse strings, will have a tremendous influence on (1) how much will be spent for R&D, (2) who will perform R&D, (3) the relative financial support to be given to basic research, applied research, and development, and (4) how national R&D missions or mission agencies will be supported. Federal purse strings will be a major factor in determining the direction and vitality of the Nation's science and technology capabilities in the future. If, as some evidence indicates, the Nation should increase its support of civilian industrial R&D, and perhaps particularly the basic research part of that, the Federal R&D budget would be a most appropriate tool for bringing about such results. But, because there are often long "lead times" involved in carrying out R&D, many science and technology policy decisions need to be made today by the Federal Government in order to impact favorably on the Nation years from now.

Because the national R&D establishment is large and its programs are complex, most Federal R&D funding decisions are made on an incremental basis, as is usual with Federal Government programs. In the future, however, what may be required for a more adequate apportionment of funds for R&D may be a more comprehensive and rationalized approach to funding than the existing annual Federal funding process (as suggested above in the subsection on the congressional authorization process and science and technology). Because this aspect of science and technology policymaking goes to the very heart of the governmental process, it may be the most difficult aspect of science and technology policy to modify, even should in-depth analysis suggest that it would be most advantageous to do so from the R&D point of view.

Another way that the R&D funding and budget process will affect national science and technology will be its size. R&D funding grew rapidly during and following World War II and particularly after the launch of Sputnik by the U.S.S.R. in 1957. After 1967, however, national R&D funding leveled off. The following figure shows these trends in both current and constant dollars:

National R&D funding trends: 1953-79



Average annual rate of change						
	Current			Constant		
Year	Total	Federal	Non-Federal	Total	Federal	Non-Federal
1953-61	13.7%	16.4%	10.0%	11.4%	14.0%	7.7%
1961-67	8.3	7.6	9.5	6.0	5.3	7.2
1967-75	5.4	2.9	8.7	-.7	-3.0	2.4
1975-79	10.0	9.1	11.0	3.5	2.6	4.5

Source: National Science Foundation. National Patterns of R. & D. Resources: 1953—1978–79. NSF 78–313. Washington, U.S. Government Printing Office, 1977: viii.

Whether the R&D position of the Federal budget should be (1) increased or decreased, (2) redistributed in a different manner, or (3) both is an extremely complex question. Upon its answer, however, depends in large measure the military and techno-economic strength and vitality of the Nation in the next 30 plus years.

5. FEDERAL REGULATIONS

Federal health, safety, and environmental regulatory agencies, such as the Food and Drug Administration (FDA), Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), Consumer Product Safety Commission (CPSC), Federal Aviation Administration (FAA), and Nuclear Regulatory Commission (NRC), administer social regulatory programs. Other agencies like the Federal Power Commission (FPC), Federal Communications Commission (FCC), Federal Trade Commission (FTC), Interstate Commerce Commission (ICC), and Federal Maritime Commission (FMC) administer economic regulatory programs. The distinction between these regulatory activities is the following:

> Economic regulatory programs, for example, control entry of firms into particular lines of business, set prices they may charge, and sometimes specify the standards of service the firms can offer. Under certain circumstances the regulations can be useful in regulating natural monopolies or providing income support. Social regulatory programs, on the other hand, are designed to correct a variety of undesirable side effects in our economy that relate to safety, health, and the environment—effects that markets, left to themselves, often ignore. Whereas economic regulatory programs typically govern the conditions of doing business in one or more industries, social regulations frequently dictate some of the operating conditions required of a wide range of industries.[25]

These two types of regulatory activity—social and economic regulation—may affect R&D and innovation in regulated industries in quite different ways. For example, in the area of social regulatory activity, the Federal Government's impact on the drug industry, mainly through the FDA, is pervasive. The reported fourfold decrease in the introduction of new drug products in the last 20 years has been attributed to this regulatory activity by some observers, although other observers attribute the decrease to the relatively few new basic discoveries in pharmacological R&D over that same period. In the area of economic regulation, on the other hand, the regulation of the telecommunications industry by the FCC probably has not stifled R&D and innovation in telecommunications technologies, although it probably has slowed down the economic development of the cable television (CATV) part of the telecommunications industry.

It has been suggested that the difference in the regulatory effects on R&D and innovation in these two cases may be attributed to the following important differences in the nature of the regulatory activities involved. The regulation of the drug industry is an example of what, to a large extent, may be called "process regulation"—regulation of the way in which the industry produces its products. This type of regulation directly impacts on R&D and innovation. On the other hand, the regulation of the telecommunications industry is an example

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[25] Economic Report of the President. Washington, U.S. Government Printing Office, 1978: 206.

of what, to a large extent, may be termed "end-product or end-service regulation." In this case, telecommunications R&D and innovation are not directly regulated but are allowed full rein by the electronics industry. Economic regulation, however, does affect the technological products produced due to the regulation of which services may be offered by the telecommunications industry, the structure of firms in that industry, and even the competitive structure of the industry itself.

Another factor to be considered in investigating the impact of regulations on R&D and innovation is the nature of the regulatory standards promulgated and enforced by the regulatory agencies. There are two types of regulatory standards. "Technical standards" specify the equipment or processes that producers must adopt whereas "performance standards" establish an expected outcome, physical or economic, but leave the choice of the products or processes involved to the regulated industry itself.

While the above discussion of regulatory factors impacting on R&D and innovation is oversimplified and a number of other factors enter in, it is apparent that (1) Federal regulation may affect R&D and innovation in some regulated industries in a significantly adverse fashion even to the extent of stifling R&D and innovations, and (2) whether adverse or not, the different types of regulations affect the R&D and innovation capabilities of different industries in significantly different ways. Also important is the fact that even where the amount of R&D per se is not decreased, the scientific or technological direction of R&D may be significantly changed from long-range, fundamental R&D with long-range payoffs to short-range, defensive R&D with only short-range payoffs.

The total effects of governmental regulations on U.S. industry are quite complex and are not completely understood today. While disadvantageous in some cases, they may be advantageous in other cases, as when they have stimulated R&D and innovation in the aircraft and environmental "clean-up" industries. In general, there appears to be increasing concern that the overall effect of governmental regulations on industrial R&D and innovation may be negative, particularly in those cases in which the regulatory process itself is unpredictable, because inconsistent over time, and characterized by long procedural delays. Currently, however, there is little firm evidence with which to substantiate this concern.

The issue of the effects of regulation on industry is currently the subject of governmental and industry study. It is one of the several political and governance factors affecting R&D and innovation which is being examined in the President's Domestic Policy Review of industrial innovation (mentioned above). Because the issue of Federal regulation and R&D and innovation is so much a part of the entire fabric of Federal governance, it may be a very difficult problem with which to deal. On the other hand, since regulation is directly a creature of legislation, it can be modified by legislation and executive branch action in response to increasing knowledge of its overall effects on industry and society, including its effects on the Nation's R&D capabilities.

Today, regulatory reform is gaining momentum in both the legislative and executive branches. On March 23, 1978, President Carter signed Executive Order 12044, "Improving Government Regulations," which directs all executive branch departments and agencies to "adopt procedures to improve existing and future regulations." Thereafter, on October 31, 1978, President Carter directed the creation of the Regulatory Council, comprised of 35 departments and agencies with significant regulatory responsibilities, to help coordinate Federal regulatory activities and expand efforts to manage the regulatory process more effectively. On February 28, 1979, the Regulatory Council published the first Calendar of Federal Regulations in the Federal Register. This is a complete list of all major regulations currently being developed by all executive branch regulatory agencies, plus major regulations being developed by many of the independent regulatory agencies.

On March 7, 1979, the Department of Commerce published in the Federal Register a "Semi-Annual Agenda of Regulations," in compliance with Executive Order 12044, which includes a list of existing rules and regulations selected for review by that department.

The Carter Administration also established in 1978 the Regulatory Analysis Review Group, comprised of representatives of the principal regulatory and economic agencies under the auspices of Charles L. Schultze, Chairman of the Council of Economic Advisers. This group has become the focus of the Administration's regulatory reform efforts.

In the 96th Congress major regulatory reform bills have been introduced to reorganize Federal regulatory agencies to prevent excessive, duplicative, inflationary, and anticompetitive regulation, and to make regulation more effective and responsive to the public interest.[26] Hearings were held by the Senate Committee on Governmental Affairs in March 1979 on Federal regulatory reform.

6. PATENT, ANTITRUST, AND TAX POLICIES

A number of other governmental policies will directly impact on the Nation's science and technology capabilities. Patent, antitrust, and tax policies are representative of such governmental policies although a number of others, like Government procurement policy, also will impact on science and technology and should be considered in any comprehensive analysis of the effects of general government policies on R&D.

Government patent policy relating to the ownership of inventions resulting from federally supported R&D is important because of the large percentage of the Nation's R&D which is supported by the Federal Government. Although the patent clause of the U.S. Constitution was designed to stimulate invention, existing U.S. Government patent policies may, in fact, stifle invention and innovation by discouraging U.S. industry from attempting to commercialize its inventions and innovations developed through the use of Federal funds. This occurs because existing Government patent policies generally provide that

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[26] For example, the Regulatory Reform Act of 1979, S. 445, introduced by Charles Percy and Robert C. Byrd on Feb. 21, 1979 and referred to the Committee on Governmental Affairs, and an identical bill, H.R. 2364, introduced by John B. Anderson et al. on Feb. 26, 1979 and referred jointly to the Committees on Government Operations and Rules.

title to inventions developed by industry employees with Federal Government support will be retained by the U.S. Government. Moreover, many Government patent policies have been developed and instituted on an agency-by-agency basis rather than one comprehensive Government patent policy. This situation adds uncertainty and administrative burdens that may discourage firms from following fruitful avenues of research and development. A reform of U.S. Government patent policy related to the ownership of inventions resulting from federally supported R&D would probably help to stimulate industrial R&D and innovation. Legislation to do this was introduced in the 95th Congress but was not acted upon. Similar legislation has been introduced in the 96th Congress.

The Federal Government's antitrust policies also affect science and technology. These policies are perceived by industry generally to prohibit U.S. industrial cooperation in most areas of science and technology, as well as in most other areas of industrial activity. In some cases, U.S. industrial firms may cooperate in supporting basic research, but whenever these activities begin to appear to be mainly commercially related applied research or development, such activities are discouraged or prohibited. These longstanding and generally beneficial antitrust policies were designed to prevent unreasonable restraints on domestic trade, monopolies, and so on. Today, however, particularly vis-à-vis the activities of countries like Japan, these policies may be becoming counterproductive from the point of view of the United States' international techno-economic relations. The Japanese Government permits industrial-government-academic consortia (often referred to as "Japan, Inc.") to exist for many commercial purposes, as in the case of the consortium supporting the Japanese electronics industry in its development of sophisticated microelectronic components. Because the United States is entering what appears to be an era of increased and very competitive international trade with Japan and countries of western Europe—involving even high-technology products—it now may be timely to investigate in depth the effects that Federal antitrust policies are having, and are likely to have in the years ahead, on U.S. industrial R&D and innovation.

Another aspect of Federal policy that affects science and technology is Federal tax policy. Because of an apparently decreasing U.S. industrial investment in long-range R&D, it may be necessary for the Federal Government to institute either short-term or long-term tax incentives to stimulate industrial investment in its own R&D capabilities. Because R&D may be looked upon by some corporate managers as a long-term investment having only long-term, if any, payoffs, when short-term financial constraints occur R&D may be one of the first corporate activities to be cut in the interest of maintaining short-term profits and earnings. To offset such corporate behavior during this and other periods of national economic difficulties, it may be appropriate to modify corporate tax policies to stimulate R&D so that the Nation's future industrial R&D capabilities are not compromised by existing economic difficulties and (perhaps short-sighted) corporate policies.

Patent, antitrust, and tax policies are examples of Government policies that will impact on science and technology. In fact, many other policies not mainly concerned with Federal support of R&D also may impact strongly on R&D. While it is impossible without in-depth analysis to suggest specific reforms, it is possible that many "non-R&D" policies could be modified to substantially enhance the Nation's industrial R&D performance. An adequate examination of relevant Federal policies would have to be comprehensive in nature because of the many countervailing effects that these several policies probably will have on the national economy in general and on R&D in particular.

F. Societal Factors

The factors discussed above which affect science and technology either "internally" or "from the outside"—science and technology education and other factors internal to science and technology, techno-economic factors, and political and governance factors—are all, in one sense, similar. That is, they are in general consciously directed or managed by either governmental or private decision- or policymakers. The factors affecting science and technology discussed in this and the following sections (societal and environmental factors) are in a sense relatively diffuse factors whose guiding principles currently may not be fully articulated. These factors may be more in the nature of "movements" rather than policies or programs. For that reason, however, they will not be less important or serious than the other factors affecting science and technology discussed already. In terms of the future, in fact, they may be more important because they may either coalesce into major, articulated policies that overshadow those policies driving science and technology today, or become militant mass movements that swamp the machinery of government.

1. ANTI-TECHNOLOGY MOVEMENTS

The anti-technology movement, to the extent that it exists, is probably deeply rooted. The human tragedies of the industrial revolution which began in England in the 1750's continue today. When machines and people come together, people often suffer. Since the early 1900's, this view of science, technology, and industrialization has changed and people (most Americans at least) now feel that science, technology and machines have truly been domesticated. Certainly, the average American's life is eased in many ways by science, technology, and the material goods produced by industry.

Since the early 1960's, however, a small minority of Americans has been rebelling against American society and against American technology in particular. This rebellion may have been partially a reaction to problems endemic to materialistic affluence, like environmental degradation, and to the technological horrors of the war in Vietnam. Perhaps another reason for such anomie is a perception that technology is really only a powerful tool—moreover, a "value free" tool—that can be used for good and evil, and more importantly, for amplifying either good or evil. Perhaps the inchoate anti-technology movement is sparked by the vision that science and technology may consequently out-distance man's ability to control science and technology for his own benefit and that the point of no return is rapidly being approached.

Science and technology have obviously changed society in many profound ways. The pill—a biomedical technology—has significantly affected the nature of the American family, the most basic unit of society and the cement holding society together. Another pervasive technological situation is the invisible cloud of possible nuclear destruction overhanging the world.

While it is probably inconceivable that the Nation through political action will turn the clock of techno-economic development back, the long-range effects of man's love-hate relationship with science and technology are uncertain. Many science fiction writers have written popular scenarios of possible technological futures. The one thing most common to these scenarios seems to be that the technological-societal situations depicted in them are either (1) unacceptable to us, the readers, and/or (2) unacceptable to the fictional characters of the future represented in the stories.

Science and technology have created many problems and opportunities for society. The view of most scientists, engineers, and science and technology policymakers seems to be that science and technology can create still more societal opportunities and solve most of its own problems. Because of the pervasive effects of science and technology on society, however, citizens themselves are now becoming concerned with science and technology and its effects. Public participation in science and technology policymaking probably will become common and may be an important factor in the future of science and technology in this Nation. Public participation in science and technology decisions may be one way to offset the tremendous internal dynamic of science and techno-economics that is often referred to as the "technological imperative."

Technology assessment (TA) is a relatively newly institutionalized technique or set of techniques to evaluate the second and third order intended and unintended effects of science and technology on society and the environment. Whether technology assessment, as currently institutionalized in the congressional Office of Technology Assessment and other organizations, will satisfy society's need to control science and technology for its own benefit is doubtful, but it does represent one form of needed societal control in the area of the applications and effects of science and technology.

A very important and difficult area for politicians and science and technology policymakers in the future will be to develop new institutional processes, like public participation and technology assessment, to aid in harnessing fully the technological imperative for man's benefit. Unless Government does this first, adversely affected citizens may support antitechnology movements that could develop enough momentum to do the same thing in a non-economic or even destructive fashion.

2. CHANGING VALUES

Societal values change over time. The basic difference today is that societal values apparently are changing much more rapidly than ever before in U.S. history. Alvin Toffler wrote a popular book based on the thesis that too rapid changes in basic societal parameters and values will cause "future shock"[27] in many persons and consequently in

[27] Toffler, Alvin. Future Shock. New York, Random House, 1970. 505 p.

society as a whole. The shock would be due to the inability of individuals and society to become stabilized or comfortable with one set of societal values and norms before another set replaces it. Much of the apparent malaise in many nations of the world today may be attributable to societal shock due to rapidly changing value systems.

Even without an apocalyptic view of rapid value change causing societal shock, societal values still may be changing rapidly enough to cause basic transformations in societal and governmental priorities in the future.

In subsection E.1, above, current national science and technology goals were discussed with a suggestion for a new goal derived from redefining national security to include techno-economic security. Such a new national goal would still be within the basic frame of reference of contemporary U.S. society. The issue here is—will societal values change so rapidly over the few remaining years of the 20th century and into the 21st century that they will impact on and significantly change the Nation's techno-economic structure as it is constituted today?

There are indications that technology-related values are changing to some extent. For example, the emerging "small is beautiful-appropriate technology" movement is based on the concept that technology should serve basic human and social needs, such as wholesome community development, rather than drive society mindlessly along tracks laid in obedience to the "technological imperative." The very subtitle of Schumacher's book,[28] "Economics as if People Mattered," suggests that some people perceive the need to change existing techno-economic values into more humanistic values.

In Chapter V, below, three scenarios of possible futures are discussed. One of these scenarios is called the "Changing Values Scenario." Possible effects of widespread changing societal values on traditional techno-economic processes are mentioned in the following terms:

> In this evolving change, a "self-reliance" ethic likely will replace continued reliance on, and growth in, socio-economic and political system complexity. The concept of quality of life will remain a subject of ineffective public discussion, but the dominance of growth will slowly give way to emphasis on "enrichment" of life. The importance of the family will return—redefined to include all close personal and living arrangements.
>
> The emphasis on enrichment will result in a paradigm shift in the economy—reflected in new consumer spending pattern and resistance to new and/or high technology products which challenge the self-reliance ethic. Traditional small businesses and low-technology industries will flourish, while giant corporations will struggle to attract and keep talented personnel at all levels.

Assuming changing values, a question remains—what would drive significant and rapid changes in societal values if they were to occur? In a word, the answer probably would be "techno-economic backlash." If the negative effects of a rapidly developing techno-economic society are perceived by many people to outweigh the positive effects, basic

[28] Schumacher, E. F. Small Is Beautiful: Economics as if People Mattered. New York, Harper and Row, 1973. 290 p.

value shifts would occur. Today there are signs that old and long-established societal values are being eroded rapidly, although it is uncertain what future values will replace them. Much current evidence indicates that a large part of the older value system—for example, the so-called Protestant work ethic—may be in the process of irreversible change. The implications of a techno-economic society's loss of a broadly-based ethical foundation for hard and productive work are enormous and may suggest part of the reason for the growing strength of Japanese and western European international techno-economic competition vis-a-vis the United States. It is held by many historians that most societies grow, stabilize or mature, and then decay—generally from internal corruption. It is not inconceivable that the United States may be entering either its period of mature stability or showing the first signs of decay.

The possibilities for exploring all the implications of changing societal value on existing techno-economic society are almost endless. It is enough for this discusion to indicate that some signs point to basic societal value changes that could transform American techno-economic society as it is now constituted into what may be termed either (1) more humanistic, for example, from an "appropriate technologist's" point of view or (2) decadent, from the point of many of today's captains of industry. The future of techno-economic society could, indeed, be "shocking" if the "technological imperative" runs head on into the "humanistic imperative."

G. Environmental Factors

Much of the Nation's environmental degradation is caused by the waste products and industrial processes of its complex and pervasive techno-economic system. Three major problems caused by the environmental effects of a techno-economic society are (1) the danger of approaching the earth's finite capacity to absorb man-made wastes efficiently and safely, its "carrying capacity," (2) natural resource depletion, and (3) the economic burdens resulting from the social and economic costs involved in using, protecting, preserving, and restoring the environment, including the costs of using natural resources for man's material needs.

The Nation, and particularly Congress, appears to be dedicated to conserving the Nation's natural environment to the greatest extent possible consistent with other national goals, such as continued techno-economic growth. The methods chosen to do this involve allocating the social and economic costs involved in environmental use or abuse to the major societal sources of such use or abuse, like industrial manufacturers.

The evolving system of allocating environmental responsibility and cost has caused some industrial manufacturers, for example, to expend large amounts of money on techniques and equipment to ameliorate pollution or to clean it up. The effects of this requirement on industrial R&D is sometimes positive and sometimes negative. It has been positive in cases like that of the "environmental clean-up" industry, where industrial R&D has provided useful products to protect the environment. It sometimes has been negative in the sense that some industries have had to reallocate limited R&D funds from primary, profit-oriented R&D to "defensive R&D" in order to cope with governmentally-imposed environmental requirements.

While the net effect of governmental environmental requirements on the current state of industrial R&D is uncertain, it is certain that the costs of protecting the environment are being borne by industrial firms to a greater extent today than was the case in the past, and the likelihood is for this trend to continue. Unless U.S. industry meets its responsibility to protect the environment, deep-seated environmental protection and/or antitechnology movements could result. On the other hand, excessive governmental requirements to control industrial environmental effects could cause extreme financial hardships in some industries and stifle R&D or redirect it into "non-productive" areas in other industries.

What is likely to occur is that under Federal (particularly, congressional) direction, a practical balance will be achieved between environmental protection and industrial techno-economic activity. Because the carrying and resource capacity of the earth appears to be enormous, extreme limits on U.S. industrial activity are unlikely to result from reasonable efforts to protect the environment. Environmental concerns probably will continue, however, to be an operating constraint on business and hence an additional cost of doing business in most areas of techno-economic activity.

The major future environmental danger to the United States would seem likely to come from another direction—in a broad sense, from exponentially increasing world population and the apparently concomitant raising of material expectations of many of the world's peoples. The Earth is a finite system that, enormous as it is, can only sustain finite populations which may be of differing sizes under differing techno-economic conditions. The rest of the world is part of the natural environment of the United States. One need not be a "limits to growth" doomster to be concerned about the ability of the carrying and resource capacity of the Earth to absorb multiples of the Earth's current four billion person population. At current population growth rates, those four billion persons will become eight billion persons in about 30 years. No one really knows if man's worldwide socio-techno-economic systems can cope with that population strain. Fortunately, there are indications that this population growth rate is decreasing worldwide. "Technological fixes," like birth control technologies, might theoretically be able to solve the world's population problem, but cultural factors may nullify the use or effectiveness of such technologies.

The long-term environmental factors which will threaten the United States probably can be summed up in what may be termed the total world "population-food-natural resource equation." The equation must balance or the total world environmental system will degrade. In terms of human life that probably would mean increased suffering and death of many people in several parts of the world.

H. Recapitulation

In the preceding sections of this chapter, some 22 factors internal to science and technology or impacting on science and technology from the outside are identified and discussed. Some of these factors are broad, major issues and some are narrow but insistent issues. Whatever their dimensions, in one sense they have to fit together like the varying sized pieces of a jigsaw puzzle for a complete picture of national science and technology to emerge.

In a jigsaw puzzle, the most important aspect is the organizing principle underlying the whole puzzle. In the case of science and technology, the organizing principle may be national science and technology policy and management as discussed in subsection E. 2. Without such an organizing principle, many parts of the Nation's science and technology system may be made optimal while the science and technology system as a whole may suffer from an unbalanced allocation of R&D resources.

If science and technology continues to be fundamentally important to governance and to the Nation's techno-economic society, science and technology policymaking probably should be improved. To optimize science and technology policymaking at the Federal executive branch level may involve a comprehensive and in-depth rethinking and restructuring of the national science and technology policy establishment. It also may involve the establishment of a new science and technology coordinating and management organization in the executive branch with more cross-cutting authority to require actions throughout the operating levels of U.S. departments and agencies than is currently permitted.

III. Major World Problem Areas

The preceding section discussed what may be termed the "systemic" factors characteristic of the U.S. socio-politico-techno-economic system. If this system is taken as a manageable entity, the rest of the world, for purposes of discussion, may be considered to form the outside environment of the system. What is this "environment" like? How does it impact on the U.S. techno-economic system? These questions indicate another dimension of the role of science and technology in the future—the role of science and technology in a global context as a contributor of solutions to major world problems.

A. Examples of Major World Problem Areas

An examination of a number of futures-oriented studies which investigated major world problem areas suggests several principal categories of major world problems which are not less important for being fairly obvious. The following is a listing of major world problem areas with two or three examples under each of specific problems and opportunities which likely will face science and technology decisionmakers in the years ahead. The listing is not meant to be comprehensive, but rather suggestive of the many world problems and opportunities in which science and technology likely will be involved during the "outlook period" of this Science and Technology Outlook—a period beginning in about 5 years and extending 15 or 30 years in the future.

World Population Growth and Aging Populations
- Population and fertility control research
- Research on problems of aging populations
- Research on life-extending technologies

Food: Agricultural Production and Distribution
- World shortages of food due to low production and maldistribution
- Weather modeling for agricultural purposes
- Development of the technology of aquaculture

Foreign Affairs and Military Security
- Space-based "beam" weapons
- Joint military-civilian technology development
- Nuclear proliferation and safeguards

Techno-Economic Security and Viability
- Domestic barriers to technological innovation
- Decrease of dominant U.S. position in aeronautics and electronics vis-a-vis Japan and western Europe
- The computer revolution

Energy
- Impending supply crisis in oil and gas due to national depletion
- Reevaluation of the need for breeder reactors and fusion power

Environment
- Cumulative effects of pollution
- Regulation of weather modification
- Resolution of the nuclear energy-environmental impact issue

Non-Energy Resources and Materials
- Raw materials shortages
- Use of organic renewable resources
- Deep ocean mining

Political and Societal Tensions and Breakdowns
- Effects of stress on societies and individuals
- Growing need for appropriate technology
- Need for social innovations

Health and Biosciences
- Potential conflicts regarding nonconventional (holistic) health care
- Nutrition research
- Bioethics

Human Settlements
- Need for new technological opportunities in housing
- Potential for new urban violence

Transportation and Telecommunications
- Alternative automotive power system R&D
- Need for new technological opportunities in urban transportation
- Telecommunications effects on postal service, publications, and business operations

Education
- Aging of academic scientists
- Adequacy of science and engineering manpower levels
- Use of educational technologies

Governance
- Limits to the management of large, complex systems
- Participatory democracy by means of computerized elections and referenda

Science and Technology Imperatives and Prospects
The potential use and misuse of "consciousness technologies"
Opportunities in social and behavioral sciences
Catastrophic experiments

Neither the above taxonomy of world problem areas nor the examples of science and technology problems and opportunities under each category is definitive. Its purpose is to emphasize that science and technology will impact on, and will be driven by, major world problems in much the same way that they will impact on and will be driven by the "systemic" factors discussed in Chapter II. The ramifications of this situation are that the long-term outlook for science and technology will be largely determined by the interplay of science and technology with major world problem areas. Neither subject can be analyzed in isolation if sound policy conclusions and decisions are to be reached. Particularly, the outlook for science and technology will not be determined either by (1) U.S. scientists and engineers, (2) U.S. business and academic leaders, or (3) U.S. Government science and technology policymakers alone pursuing their own interests. It will be determined by these persons and the rest of the world's policymakers together in response to, or in anticipation of, world problems and forces like those outlined above.

B. Foresight and S&T Management "Linkages"

The ability of national policymakers to formulate adequate socio-techno-economic policies having long-term perspective would seem to hinge on the Nation's (governmental and/or private) ability to develop adequate techniques and processes for policy foresight in the areas of science and technology as well as in economic, social, environmental, and other world problem areas. Equally as important, and probably even more difficult to institute, would be strong and workable management "linkages" between (1) the analyses and intelligence provided by policy foresight specialists and (2) the real-time and Realpolitik requirements, for example, of Members of Congress for legislative inputs and officials of the executive branch for inputs for programmatic decisionmaking. The effectiveness of science and technology in the future may well depend largely on whether science and technology inputs can be acted upon by decisionmakers in time to ameliorate emerging problems before they develop into major problems.

The institutionalization of foresight information collection and analysis seems to be developing reasonably well today both in government and in the private sector. The major operational weakness associated with foresight now seems to be in the lack of a system of formal "linkages" to decisionmakers. The establishment of strong management "linkages" between foresight specialists and policy decisionmakers would seem to be central to optimizing the Nation's science and technology capability in order to deal with major world problems.

It is easy to give examples of how science and technology policy formulation may not be working well today. The decades-long controversy over the long-term effects of nuclear power development—which has led to a significant slowdown in nuclear power plant deployment in the United States, and the Rasmussen Report and the newer "anti-Rasmussen Report"—is a case in point. Scientists and engineers have contributed to both sides of the controversy. Science and technology policy decisionmakers, as a group, are still uncertain as to how to deal with nuclear power production and its related problems.

The essential questions will include—is this situation endemic to science and technology foresight? Or will science and technology foresight be better institutionalized to cope with such broad S&T-based societal issues? The answers to such questions are important if the United States is to be able to make long-range plans involving science and technology programs having long research and development lead times, such as nuclear power plants, or having potential long-term effects, like the cumulative effects of pollution. Unless science and technology foresight processes can be developed to the point where they will (1) contribute more to the validation of foresight intelligence and (2) reduce this information to useful real-time and Realpolitik policy inputs for governmental and private decisionmakers, the long-term outlook for science and technology is likely to be that they will often function in a reactive mode—which may mean a crisis mode—to the major world problems outlined in this chapter.

The development of an effective, operational system of S&T foresight-policy linkages will no doubt be quite difficult, however, it may be one of the most important areas for the Congress to examine in the immediate future.

An approach to establishing an operational system of science and technology foresight-policy linkages might be to institute, in an appropriate high-level governmental structure, a formal set of procedures through which foresight information could be collected, evaluated, stored, and then disseminated, for example, as either (1) trend extrapolations and/or forecasts in a standardized format, (2) interactive, computerized data programs permitting manipulation of data by means of video screen terminals, and (3) special reports on specific topics requested by policymakers which would be prepared by foresight specialists.

An important aspect of such a linkage mechanism might be the establishment of a set of criteria by which to evaluate the validity of trend data and forecasts in light of the requirements of national policymakers. One procedure might be to ask a series of questions—all of which would have to be answered adequately before the trends and forecasts would be considered reliable enough for use by policymakers. By establishing a system to evaluate trends and forecasts and to transfer this information directly to policymakers, the range of uncertainty involving foresight policy subjects might be reduced, perhaps thereby improving and expediting policymaking in regard to a host of policy areas requiring program implementation, or having societal effects, in the near-term future (over 5 and up to 15 to 30 years in the future).

One set of important questions concerning policy and the future has been suggested by Robert W. Lamson.[29] Because such questions give

[29] Lamson, Robert W. Checklist of Important Questions Concerning Policy and the Future. Unpublished: 3–6.

the flavor of the types of questions discussed in the preceding paragraph, the major categories of questions are outlined here:

1. Alternative futures
   - Possibility
   - Probability
   - Impacts
   - Risk
   - Contingency
   - Uncertainty
   - Saliency
   - Desirability
   - Controllability
2. Desirable future worlds
3. Problem, causes, impacts
4. Options and impacts
5. Values
6. Implementation
7. Costs, benefits, risks
8. Evaluation
   - Criteria and methods
     - Feasibility
     - Effectiveness
     - Efficiency
   - Comparison and trade-off
9. Priority
10. Recommendation

If policy issues involving major futures components could be subjected to a rigorous set of questions, similar to the above, administered by a high-level governmental structure, then policymakers might have a source of fairly reliable trends and forecasts upon which they could depend to a reasonable degree and which would also serve as a benchmark for evaluating trends, forecasts, and other foresight analyses prepared throughout Government, academia, and the private sectors. If such a structure could be created, earn the respect of policymakers, and be used by them, a practical and effective system of science and technology foresight-policy linkages might result.

IV. Emerging Technological Developments

Another aspect of science and technology needs to be investigated in the development of a comprehensive Science and Technology Outlook. In addition to those factors internal and external to the operation of the national science and technology "system" (Chapter II), and the role of the U.S. science and technology system in a global context as a contributor of solutions to major world problem areas (Chapter III), is the emergence of specific scientific and technological developments, driving or deriving from the above factors, which have the potential of significantly effecting society in the future. A few selected examples of such emerging technological developments are discussed in the following paragraphs. The purpose of this discussion is to highlight the need for future technology forecasts and impact assessments to investigate in depth these and similar emerging technological developments.

The representative emerging technological developments discussed below are: [30]

1. Birth Control
2. Food: Aquaculture
3. Health: Combating Future Cancers
4. Biosciences and Bioethics; DNA
5. Microelectronics: Computers and Telecommunications
6. Transportation: Short-hop STOL Airliners
7. Technology-abetted Political Participatory Systems
8. Energy: Oil Shale
9. Energy: Fusion
10. Space Colonization

A. Birth Control

Perhaps the major problem likely to face the world as a whole in the future is the food-population balance—or imbalance. Although the problem is likely to be most severe in Asia, South America (including Mexico), and Africa, even in the United States the impact of overpopulation may be felt acutely and immediately in future urban environments, where the social issues of poverty, illiteracy, crime, hunger, disease, depression, and general unhappiness are compounded by overcrowding. Problems associated with overpopulation affect the community, as well as the family and other social units within that community.

Although much work has been done on birth control technologies to date, "current [birth control] technologies cannot be regarded as adequate to meet individual or societal needs in either industrial or developing nations." [31] Moreover, because of the required lead time in implementing new medical technologies for human use, any method of contraception or birth control that is going to be utilized by the 1980's must be at the advanced stages of testing now. The message is clear—to meet the overpopulation problems of tomorrow, R&D on birth control must continue to be carried on diligently today.

Of course, birth control is not a simple issue in which a mere "technological fix" will be sufficient. The major problem, and the main focus of the report cited above, is summarized in the following statement:

> The heterogeneity of personal, cultural, religious, and economic circumstances in human life, as well as the varying needs of individuals at different stages in the life cycle, impose diverse demands upon the technology. It is thus likely that there will never be an "ideal" contraceptive for all circumstances. What is needed is a broad array of contraceptive methods that require less complex distribution systems that are safer, less discomforting, and more convenient than current methods; that combine high acceptability with high continuity of use; and that are suited to the diverse requirements imposed by the diversity of conditions throughout the world.[32]

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[30] These examples are taken from—and liberally quote—articles by Vikki Zegel, Christopher Dodge, Jo-Ann McNally, Marvin Kornbluh, George N. Chatham, Paul Rothberg, Lani Raleigh, and Marcia Smith of the Science Policy Research Division, and Keith Bea of the Foreign Affairs and National Defense Division, of the Congressional Research Service in the following three CRS Reports: Selected Profiles of Future Tchnology (78–67 SPR), Mar. 17, 1978; Selected Profiles of Future Technology in Urban Settings: Physical and Environmental Developments, Volume I (78–105 SPR), April 19, 1978; and Selected Profiles of Future Technology in Urban Settings: Informational and Behavioral Developments, Volume II (78–106 SPR), Apr. 19, 1978.

[31] Greep, Roy O. et al. Reproduction and Human Welfare: A Challenge to Research. The MIT Press, Cambridge, 1976: 4.

[32] Ibid.

B. Food: Aquaculture

Where will the food come from to feed the world's future doubled or quadrupled population? One possibility is aquaculture—a developing but still infant technology.

On an international scale, the United States does not rank very high in the aquacultural production of fin fish and other fisheries products. China leads the world in the production of fin fish, most likely due to the widespread cultivation of carp in that country. India and the U.S.S.R. also occupy leading positions in aquacultural production.

Between 1966 and 1976, world aquacultural production increased by 20 percent. This latter figure may double by 1985 and double again by the year 2000. This favorable growth projection does not extend to the United States where aquaculture has been characterized as "stagnating."

The consensus of opinion is that the total theoretical potential of aquaculture is high. Whether that potential can be attained and sustained is problematical. In addition to technical and economic difficulties to be overcome, global pollution is an increasing threat to future aquacultural enterprises. Furthermore, it seems likely that maximized production of aquatic foods can be achieved only if aquaculture is emphasized and its development is aided by consortia of government, academic, and industry-supported research and development programs. Given such support, many experts feel that in the future the harvest of cultured aquatic stock may come to rival the traditional, barely managed harvest of wild stocks.

C. Health: Combating Future Cancers

Many cancer researchers estimate that 60 to 90 percent of all cancers are environmental in origin. Recently, Dr. Bruce Ames, a noted carcinogen researcher from the University of California at Berkeley, predicted that a cancer "epidemic" is coming because of the chemical production boom which occurred in the 1960's.[33] It appears to be entirely possible that the incidence of cancer may increase dramatically in the next 5 to 15 years because of increased exposure in the 1950's and early 1960's to factors which have been linked to cancer.

An epidemic or even a noticeable increase in the cancer rate would mean more cancers, and presumably more deaths, unless cures are found. In addition to the primary impact—increased and widespread human suffering—there would be indirect economic costs involved. For example, the economy would likely suffer if stricter controls on pollution and chemical production would cause a decrease in innovation and new product development with the increased cost being passed along to consumers. A higher incidence of cancer would also hurt the economy by increasing medical costs and by more lost work days because of illness and death.

Current public reaction to carcinogenic risk raises doubts that the public will voluntarily avoid carcinogenic substances, assuming that they are aware of such risks. For example, even though cigarette smok-

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[33] Bruce Ames Tells NCI Advisory Group that a Cancer "Epidemic" Is Coming. Pesticide and Toxic Chemical News, Sept. 21, 1977 : 15.

ing has been shown to increase the risk of lung cancer, many people continue to willingly expose themselves to such a risk despite all efforts to encourage them to stop voluntarily.

If the incidence of cancer becomes even greater than it is, it is possible that even more resources will be devoted to cancer research in the future.

D. Biosciences and Bioethics: DNA

DNA recombinant molecule research is a relatively new technique that employs special enzymes to "cut" the DNA molecule and to "recombine" the various sections, thereby arranging the fragments into a new sequence of hereditary material.

The potential of DNA research for great benefits in medicine and agriculture has been contrasted with speculation regarding potential hazards and concerns about the morality of research that involves genetic manipulation. For example, the potential medical benefits to be realized if insulin could be mass produced in a "biological factory" system, through genetic recombination techniques, must be weighed against the potential risks to health and/or the environment if an uncontrollable pathogen were to be inadvertently created in the process of the research. Corrective gene surgery (a far more distant potentiality) for genetically defective human beings must be viewed in the total context of attaining the capability to alter the genetic makeup of the human species. There are those who feel that this particular research technique should be stopped entirely because of the potential for hazardous consequences.

An issue not specific to the DNA controversy, but highlighted by the debates stimulated by this research field, is whether the Nation is to begin a more intensive regulation of basic research and, indeed, whether the scientific community has reached the point where public prohibition of the search for knowledge should be considered. From this perspective, the DNA issue has forced an examination of questions which deal with what research should be prohibited, who should make the decisions on prohibition, and how these prohibitions should be enforced.

E. Microelectronics: Computers and Telecommunications

With microelectronic fabrication, electronic circuit elements and their interconnections are manufactured in a single crystal of silicon—called a silicon chip. When thousands of circuit elements are integrated on one chip, the integration is said to be large-scale, and the circuits are termed large-scale integrated (LSI) circuits. A microprocessor, which is the central arithmetic and logical unit of a digital computer, fits on a chip; other chips are built as memory devices to hold thousands of bits of information.

The substitution of integrated microelectronic devices for discrete elements has quite a number of advantages including: (1) Reducing manufacturing costs considerably since both labor, materials, and floor space are saved; (2) making for greater reliability than solder joints and connections; (3) consuming less operating power; (4) requiring less air conditioning; (5) permitting greater operating speed in application; (6) permitting tiny, compact, and portable electronic devices to be fabricated; and (7) requiring less intermediate testing of applications. Many of the technological achievements in the 1970's have depended on microelectronics.

The potential applications of microelectronics are so numerous that practically all aspects of life in the forthcoming decades will be influenced by its impact. In business offices, for example, desk-sized computers are likely to become almost as common as typewriters. A new generation of powerful measuring instruments and control devices are likely to emerge. In industry, microelectronics will make possible a new generation of "robot arms and hands" capable of factory-assembly operations heretofore too complex for mechanization. These robots will be keyboard manipulated. Microelectronics in automobiles will provide many new services and potentiallly contribute to more efficient fuel use. In the home, the rate of progress in microelectronics suggests that in about a decade many individuals will possess a notebook size computer with the capacity of a large computer today, but much simpler to operate.

All of these probable future increases in processing capacity, accuracy, and data manipulation at decreasing cost will not only extend traditional equipment applications of electronics, but are likely to bring qualitative changes in the way human beings interact.

Synergisms in the fields of microelectronics and telecommunications suggest that a good deal of intelligence is likely to be built into communications devices. Emerging today, for example, is a powerful blend of computer and telephone technologies called the computer controlled private branch exchange (PBX), also called the computerized switch or the "intelligent exchange." The new PBX is made possible by the advent of low-cost, high-performance, large-scale integrated (LSI) circuits. These developments in the construction and application of the telephone will have significant impacts on the costs of doing business in urban areas and will probably have a beneficial effect on urban congestion by reducing the need for personal visits. Further, many of theforthcoming developments in telephone technology will facilitate the location of more and more business outside of urban areas.

Other emerging telecommunications technologies include the video telephone, under development for many years, which will have the capability to display still images of documents in a clear and readable manner and in such a way that viewers at both ends of a telephone line can point to items on the screen. The use of video telephones is likely to increase over the next 10 to 15 years—primarily because their costs are expected to decrease significantly along with an improvement in quality and reliability.

Television channels of various types are also likely to become more widely used as substitutes for physical travel to meetings, classes, conferences, and even to jobs. As the costs of energy increase, the costs of transportation will also rise. Television channels will be increasingly regarded as cost-saving devices and strain-reducing mechanisms rather than as luxury items or status symbols. Teleconference rooms, designed for meetings via telecommunications links, will probably become commonplace in business.

These and similar advances in microelectronics and telecommunications, and in synergisms between the two, suggest that computation and telecommunications in the near-future are likely to develop to such a degree that personal and business interactions could significantly alter traditional work-habitat-leisure-transportation relationships.

F. Transportation: Short-hop STOL Airliners

Today we see the results of powerful trends which have caused most of the Nation's heavily used air terminals to be so remote from population centers that people spend as much time getting to and from airports as they do in the air. Land requirements are large for major terminals and land is less expensive in areas remote from the cities. Remote siting also reduces noise complaints.

Today's system emerged from an almost continuous emphasis on efficiency for high-speed, long-range trips. It is therefore poorly suited to about one-half of the market which is for trips of 500 miles or less. As often as not, a short trip involves travel to a terminal which is not located at the city desired, a situation calling for additional surface travel. In brief, today's system is poorly suited to short-haul travel, often requiring total travel times which exceed the travel of the same trip by a surface system. From an economic point of view, it would appear that the characteristics of today's system cause it to be unsuitable for what is probably the largest share of the potential airlines market. Therefore, the long-standing trend toward high-speed, long-range flights has caused a neglect of a market greater in potential size than the one being served.

One solution to the problem of neglected local-travel and short-haul markets and remotely located air terminals is a system of small convenient airfields from which special aircraft capable of short takeoffs and landings (STOL) are operated. The Federal Aviation Administration (FAA) has urged the development of such a system for more than two decades. Experimental trials made by airlines have also demonstrated the workability of the STOL transportation system. Yet throughout all of this time, the STOL system has remained a potential solution which many persons want but no one can implement. No one will develop or buy STOL airplanes for use on an airfield system that does not exist and conversely no one will develop a STOL airfield system for nonexistent STOL aircraft.

A close look at what is happening today reveals that the much sought after short-haul STOL system is indeed slowly emerging. In fact, STOL-sized airports do exist after all. They are called General Aviation Fields and there are about 12,000 of them in the United States.

By about 1985, the most rapidly growing category of commercial air service probably will be the short-haul commuter system. By 1995, the traffic demand probably will have created a growing market for specialized 100- to 200-passenger STOL transports. It is probably reasonable to forecast that a STOL system will come into existence in about 20 years.

G. Technology-Abetted Political Participatory Systems

By the year 2000, the political pressures on elected and appointed public officials may be compounded to unmanageable levels. To ameliorate this situation, a variety of procedures for policymaking, rulemaking, and administration are being applied to the public sector. One of these procedures is public participation. Public participation can be an aid to embattled representatives, isolated administrators, and interested citizens alike. The purpose of public participation is to complement and extend representative democracy, and improve the service of the public sector.

To facilitate the incorporation of citizen participation efforts in day-to-day public affairs, many technologies and techniques could be used to increase communication between public officials and citizens. One such technology, interactive cable television, has a potential for large-scale application to citizen involvement processes 10 to 20 years in the future.

With the aid of a computer terminal plugged into a cable television (CATV) set, it has become possible to turn today's broadcasting system into a two-way, interactive communications device. The terminal contains a series of buttons that provides the viewer with the opportunity to register his vote on any issue displayed on the screen. These votes are immediately assimilated into a centralized computer for analysis and counting.

Interactive CATV may be used to conduct informal opinion polls of citizens that would not only indicate how a majority of the respondents felt on an issue, but would register the degree of variance of minorities from the majority in the community and the perceptions shared by the minority viewpoints. Also, with its capability to "narrowcast" or communicate only with specified members of the audience (for example, doctors, residents of a specific zone, parents of school children), it would be possible to identify and poll specific local areas with parochial interests.

The technology, however, has apparently not advanced to the stage where the device could be used as direct input mechanisms for voting. There are many questions of security, public availability, and system reliability that would have to be addressed before it can be used in this capacity. Still, by 1990 or 1995, the potential for using this technology in policymaking and planning may be realized, particularly on the local level.

H. Energy: Oil Shale

Energy problems likely will plague the Nation for many years. Consequently, all alternatives to imported petroleum must be carefully considered and even, from time to time, reconsidered. One of these alternatives is the huge energy potential locked in the oil shale deposits of the western United States—sometimes referred to as "mountains of black gold." The quantity of oil that may be extracted from shale is more than twice the quantity of oil contained in the Middle East. As the United States shaped its national energy strategy, however, increased attention focused on the problems of shale development rather than on the potential offered by that resource. Consequently, the prospects for commercialization began to dim.

Today, the outlook for shale oil production is rather bleak in terms of significantly contributing to U.S. petroleum needs. By 1985, shale oil is likely to contribute less than one-fourth of one percent of the Nation's oil needs. Even when an industry emerges, its growth is expected to be slow and gradual. Commercial-scale projects have not yet proven to be enviromnentally acceptable or economically competitive.

The first commercially produced shale oil is likely to be extracted by underground technology, called in situ processing. Using this technique, the shale is burned underground and shale oil is pumped to the surface. An industry using this technology and producing 50,000 barrels per day would result in few of the impacts typically envisioned for a large scale oil shale industry. Manpower requirements are relatively small for an in situ plant, thus, few adverse social and economic impacts are expected. Consumptive water use for an in situ industry is much lower than that required for an industry processing shale above ground. Surface water contamination might be engineered to be minimal with dikes and water recovery systems. A major environmental concern of in situ processing is the potential pollution of underground water supplies.

If an industry producing 50,000 barrels per day would prove to be competitive and environmentally acceptable, many expect that there would be increased investments in shale plants.

Taking such factors into consideration, the oil shale industry in the near-term future (about 1985) is expected to be small and localized primarily in northwestern Colorado. A major policy issue, therefore, is what will the United States do in the long-term future with its "mountains of black gold?"

I. Energy: Fusion

Nuclear fusion may be a very important future source of national energy production. The advantages of nuclear fusion power appear to be that it has comparatively fewer environmental problems than current fission plants and relies on low-cost, readily available, inexhaustible fuels. The implications of fusion power for national security and the environment are therefore substantial.

The difficulty in achieving nuclear fusion is that such reactions do not begin to occur until the mixture of deuterium and tritium (isotopes of hydrogen) reaches an extremely high temperature, so that atomic nuclei collide with sufficient force to overcome their mutual repulsion. At such temperatures all matter exists in the so-called "plasma" state. Both magnetic confinement and inertial confinement fusion reactor designs have a host of theoretical and engineering problems that must be solved before fusion becomes a practical alternate technology. The major problem in fusion reactors involves understanding and predicting plasma behavior. Other problems require further knowledge of materials and involve the development of large superconducting magnets, magnet shields, and system coolants. A problem critical to laser (inertial confinement) fusion schemes is the further development of lasers.

Although there are many problems to be solved before fusion power returns more energy than it uses, forecasts hold some promise. Experts predict that commercial fusion power could be available by the year 2030. A basic science and technology policy issue is thus clear—can the Nation maintain an effective national commitment to fusion energy R&D over what may be a 50-year period?

J. Space Colonization

Not all emerging technologies are responses to problems. An example of a significant response to an opportunity is the case of space colonization.

Dr. Gerard O'Neill of Princeton University has proposed building a space colony, at one of five points in space at which the gravitational forces of the Earth and the Moon balance, to accommodate as many as 10,000 people as well as much of the industry which now pollutes Earth. In addition to these possible advantages, O'Neill suggests that the colony be used as a manufacturing site for satellite solar power station (SSPS) arrays. The arrays could be built at the colony and then transported to Earth orbit where they would collect energy from the Sun, convert it to microwaves, and beam it to receiving antennas on Earth.

The O'Neill scenario calls for constructing a core colony from materials mined on Earth and transported into space by specially designed launch vehicles. The remainder of the colony would be built from minerals obtained from the Moon. Some proponents of the concept assert that a small colony could be erected by 1995.

Another aspect of space colonization is sociological. If the social aspect of space colonization is not studied prior to a commitment to build space colonies, with due regard for the complex personal interrelationships which are bound to develop in a confined area in the harsh environment of space, the technical portion of the program may be in vain.

Perhaps the basic science and technology policy issue in regard to space exploration reduces to determining the appropriate level of support, given the Nation's limited funds and resources, for extraterrestrial human development in the face of the many unsolved problems in human development on Earth.

V. Basic Assumptions: Scenarios

Every analysis has a set of basic assumptions, either explicit or implicit. Often the basic assumptions, even if implicit, are the most important and determining factors in the analysis. In a comprehensive Science and Technology Outlook, basic assumptions must themselves be examined and not taken as "givens."

One way to examine basic assumptions related to a Science and Technology Outlook is to construct several scenarios which incorporate alternative sets of basic societal assumptions. For example, the most obvious—although not necessarily the most probable—basic societal assumption is that these principal parameters of the global (or at least American) socio-politico-techno-economic system will remain fairly constant over the immediate and near-term future, the next 30 or so years. Another way of saying this is that the future will be mainly characterized by extrapolations of existing trends. For purposes of discussion, this set of basic assumptions has been incorporated into a one-page narrative statement called the "Extrapolative Scenario." It is set forth below with two alternative scenarios entitled "Changing Values Scenario" and "Discontinuity Scenario."

The Changing Value Scenario incorporates another set of possible basic assumptions—determined in this case by a shifting of social consciousness from social goals (like 200 years of the American work ethic) to a significantly different value system—perhaps characterized by greater personal allegiance to individual self-fulfillment than to existing recipients of allegiance, such as national political systems and corporations.

A third possible scenario of society's basic structure is the "Discontinuity Scenario." This scenario encompasses major breaks with the past, whether caused by cultural, natural, man-made, or accidental factors. For example, a rapidly-developing world food-world population imbalance, a world war, or even a major societal upheaval would exemplify a major societal discontinuity. Such discontinuities would upset the world system to the extent that today's basic societal assumptions would no longer be true, or would be in danger of significant and rapid change.

These three scenarios represent one attempt to suggest that basic assumptions underlying a Science and Technology Outlook have to be examined from time to time because they are subject to major changes within the time frame of the Science and Technology Outlook itself. Although the three suggested scenarios are reasonable alternatives, they are not the only ones—or even the most likely ones—that can be envisioned. While science and technology will in part determine the texture of the future, in larger part they will operate in response to the basic thrust of society in the years ahead. If science and technology policymakers can understand the broad outlines of the future, they can most adequately develop and implement science and technology policies that will reinforce beneficial trends and ameliorate detrimental trends.

The three scenarios are discussed below. These scenarios are not predictions of what is likely to occur or what is desirable. Rather, they represent three of many possible alternative "story lines" created for illustrative and analytical purposes only.

A. *Extrapolative Scenario*

The United States was created and developed under conditions of (1) abundant and cheap natural resources, (2) relatively cheap labor, (3) the availability and transfer of industrial technology from Europe, (4) relatively small social and governmental overhead, and (5) a democratic, private enterprise spirit.

Since the end of World War II, these conditions have changed and will continue to change significantly: (1) Natural resources are increasingly scarce and expensive, both domestically and internationally, (2) U.S. labor is increasingly highly paid and internationally noncompetitive, (3) an aging U.S. industry (with some notable exceptions) seems to be increasingly unable to adopt, adapt, or innovate profitable industrial technologies, (4) the Nation has become "burdened" with an enormous social and governmental overhead which includes government safety, environmental, and health regulations, welfare, Social Security, the defense and Civil Service establishments, and so on, (5) and a pervasive big government—big business—big labor symbiosis seems to have stifled industrial techno-economic competitiveness vis-a-vis European and Japanese industrial efforts. Continuing large U.S. Government and trade deficits are evidence that these conditions exist and will continue in spite of an inflation-padded trillion dollar national economy.

Of the factors discussed here, the application of science and technology, particularly Government-directed science and industrial science and technology may have the potential for being amenable to effective national management, and for creating the productivity required to offset the negative factors which appear to be considerably less amenable to management.

Due to the lack of a creative, innovative atmosphere for U.S. R&D, including the effective management of science and technology policy at the Federal level, the Nation's aging techno-industrial base will continue to lose the competitive race with the other industrialized and competitive nations of the world. The direct consequence of this will be that the United States will not be able to afford the standard of living and necessary social and governmental services that its citizens have come to expect and demand.

Fortunately, the Nation's techno-economic system will continue to be strong and resilient enough to provide the essential base for necessary social and political cohesion. A maturing populace and the continued "adequate" performance of existing systems will contribute to an era of popular acceptance of the status quo, even though that status quo may be only a modestly developing socio-economic system.

B. Changing Values Scenario

This era in U.S. and world history will be one in which a significant change in human consciousness begins to change human values and mores. The success of active citizens in changing the Nation's racial policies, its foreign policies, and its views of the environment reflect this new set of values and a new political awareness of how to achieve them. While the crusades of the 1960's and 1970's will fade, new values will continue to grow and without a focused "movement" redirect the established order.

A related phenomenon to that of shifting values is the rapidity of change, or "future shock." While the old values and mores will be shifting, the world may be moving too fast for evaluation of those changes or for formulating new values either analytically or experimentally.

In this evolving change, a "self-reliance" ethic likely will replace continued reliance on, and growth in, socio-economic and political system complexity. The concept of quality of life will remain a subject of ineffective public discussion but the dominance of growth will slowly give way to emphasis on "enrichment" of life. The importance of the family will return—redefined to include all close personal and living arrangements.

The emphasis on enrichment will result in a paradigm shift in the economy—reflected in new consumer spending patterns and resistance to new and/or high technology products which challenge the self-reliance ethic. Traditional small businesses and low-technology industries will flourish, while giant corporations will struggle to attract and keep talented personnel at all levels.

These trends seem to indicate that a major concern of the Congress in the future may be dealing with the interactions of changing technologies and social values. The Congress may be faced with a delicate choice between controlling technology to protect old-fashioned as well as newly perceived social values, while managing technology responsibly as a key part of the Nation's techno-economic machine.

C. Discontinuity Scenario

The great economic growth of the post World War II era was achieved by finessing many major problems. These problems were not resolved and their costs were not included within the framework of the socio-economic system—in a very real sense, problems were ignored and deferred to the future. The squandering of resources—both natural and human—helped to produce the great growth of the era, but as the future becomes the present, the costs have to be paid. These costs and the lead times required will become simply too great for available systems to cope with and manage.

While no single event or issue is likely to become the focal point of concern, "the system" will slowly begin to fail through a series of crises. The cumulative effects of continued industrialization will begin to impact on, among other things, health—taxing health facilities and public and private health programs. Also, the growing problems of cost and availability of energy will lead first to a decline in the energy-intensive industries, and eventually to other industries—growth will become a rare event between long periods of negative and zero growth.

Globally, the population-food imbalance, environmental deterioration (including resource exhaustion), and the possibility of irreparable nuclear world war will cause extreme stresses in the international politico-socio-economic system.

As solutions to the systemic problems seem to be beyond the traditional thinking of leaders, radical ideas will appear and develop large followings. This in turn will increase social and political tensions, thwarting the necessary consensus for public decisions and aggravating the sense that things are out of control. In this atmosphere, terrorist activities will continue to grow and the resulting responses will produce a siege mentality. Hope for expansion and further development will fade as the Nation struggles to keep existing systems working.

The Congress and the executive branch will begin to take long-range views to avert global catastrophe. A major priority of the Congress in the immediate future will be the development of a permanent governmental structure that will have the effectiveness and continuity to deal with all aspects of foresight and policy management, particularly science and technology policy management.

As mentioned above, the three scenarios set forth in this chapter are not the only reasonable ones that could be written. The reader may wish to write his own scenario of the likely future which could include elements of the three scenarios discussed here or be an entirely new one. Such an exercise would (1) force the writer to create a logical narrative framework incorporating the disparate forces which operate on, and flow from, society as a whole and science and technology in particular and (2) prompt the writer to make explicit his basic assumptions about the long-range interrelations of science, technology, and society.

The following chapter is an attempt to incorporate such a scenario with the other factors discussed in preceding chapters into a comprehensive Science and Technlogy Outlook.

VI. Examples of Other Recent Science and Technology Outlook Reports

Several other science and technology outlook studies have been carried out over the last several years. Four of these are discussed in this chapter as being representative of different approaches to developing a science and technology outlook. These four reports are:

The OSTP–NSF–NAS *Science and Technology: A Five Year Outlook* [34] which takes a *selective* look at specific aspects of (1) science and technology, like earthquakes and computer software problems and techniques, (2) science in the United States, and (3) the institutions of science and technology.

The Organization for Economic Cooperation and Development (OECD) "Interfutures" project report *Facing the Future* [35] which looks at the outlook for science and technology from the points of view of the physical limits to growth of the planet Earth and the interrelationships between the advanced industrial countries (like the OECD countries [36]) and the developing Third World countries.

The Global 2000 Report to the President [37] by the Council on Environmental Quality (CEQ) and the Department of State which attempts to project worldwide conditions with respect to natural resource availability, population, and environmental quality using existing U.S. Government data bases and computer models.

The Europe Plus Thirty Report [38] of the Commission of European Communities which looks at the future of science and technology, particularly from the perspective of western Europe, and recommends the establishment of a permanent organization to provide futures research services for the European Community.

A. *Science and Technology: A Five-Year Outlook*

Under P.L. 94–282, the National Science and Technology Policy, Organization, and Priorities Act of 1976, the Office of Science and Technology Policy (OSTP) in the Executive Office of the President was mandated by Congress the task of preparing periodically a five-year science and technology outlook. Under a reorganization of the Executive Office of the President in 1977, this responsibility was transferred to the National Science Foundation (NSF) which subsequently requested the assistance of the National Academy of Sciences (NAS) in preparing the report. In addition to Science and Technology: A Five-Year Outlook, it is anticipated that when NSF transmits the first formal, biennial five-year science and technology outlook to the Con-

[34] National Academy of Sciences. Science and Technology: A Five-Year Outlook. Washington, National Academy of Sciences, 1979. 544 p.

[35] Organization for Economic Cooperation and Development. Facing the Future. Paris, OECD, 1979. 425 p.

[36] The OECD countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[37] Council on Environmenal Quality and the Department of State. The Global 2000 Report to the President. Washington, U.S. Government Printing Office, 1980. Three volumes.

[38] Commission of the European Communities. The Europe Plus Thirty Report. 1975.

gress it also will include a set of papers prepared by selected Federal agencies, papers commissioned by NSF on selected, policy-related topics, and a summary and analysis. These latter documents are not available at the time of this writing.

The National Academy of Sciences' science and technology outlook is divided into four major sections having 11 chapters, as follows. Each chapter includes an outlook section related to that chapter.

- Science
  - Planet Earth
  - The Living State
  - The Structure of Matter
- Technology
  - Computers and Communications
  - Energy
  - Materials
- Science and the United States
  - Demography
  - Health of the American People
  - Toxic Substances in the Environment
- Institutions
  - Academic Science and Graduate Education
  - Institutions for International Cooperation

Some highlights of the outlook sections of each of the 11 chapters are provided in the following paragraphs to indicate the scope of the topics selected for inclusion in the NAS science and technology outlook.

1. PLANET EARTH

Most of the issues discussed in the outlook section center on the continuing need over the next five years for improved data collection on a global scale for most aspects of earth sciences. This, of necessity, would entail continuing international cooperation in data collection and the increased use of advanced, particularly space-satellite, data gathering technologies, like Landsat. The outlook section also discusses the U.S. climate program and ocean management as being important aspects of earth science activities over the next five years.

2. THE LIVING STATE

There has been a "remarkable burst of advances . . . propelling biology into a new era" over the last ten years and there is "no reason for this momentum to falter. . . . The potential contribution of recombinant DNA technology is hard to exaggerate." There is, however, unlikely to be an adequate understanding of diseases of cellular malfunctions, like cancer, for 10 to 20 more years. Major advances across the wide range of neural and behavioral disorders also are unlikely to be achieved over the next five years, but rapid growth in this area of the life sciences, as well as in biological research in agriculture to increase the world's food supply, will continue.

3. THE STRUCTURE OF MATTER

This outlook section discusses the likelihood for continued rapid advances in astrophysics and cosmology, the materials sciences involved in the study of condensed matter, and the study of the molecular, atomic, and nuclear structure of matter and particle physics. The report, however, is concerned about the future quality of university research personnel and facilities and the thrust of university scientific research in light of inflation, the leveling off of funding, and the decrease in academic jobs. An important trend in sciences noted in this section of the NAS study is the increasing complexity of apparatus and the extent of facilities required for certain research opportunities to be fully exploited which, in turn, is leading to more team—as opposed to individual—research. This represents a major shift in scientific research "style" that is occurring, or is about to occur, in some areas of research on the structure of matter.

4. COMPUTERS AND COMMUNICATIONS

Computers are becoming widespread for scientific, business, recreational, and other purposes. The driving force behind this proliferation of computers during the last decade has been the "amazing decline in the cost of semiconductor chips." This trend is expected to continue during the next five years and will contribute to improvements in computers and their expansion into new application areas. Major areas of computer science in the near-term future will include the development of new, more powerful computer programming techniques.

5. ENERGY

"Over the next five years, the United States will confront *basic* questions regarding its future energy *pattern.* (emphases added) . . . For the mid-term transition from oil and gas to other energy forms, the United States has in reality very little maneuverability, in both energy supply and use." What are required, according to the report, are "new energy technologies and the political will to develop and use them responsibly," both of which will be difficult to obtain. Overall, the report holds that energy conservation deserves the highest priority over the next several years. The second important issue to be settled within the next five years is how to handle the transition from oil and gas to other energy supplies. The development of alternative energy sources in the next several years, particularly coal, will cause some significant environmental and health problems; water availability to support energy development is also a problem within this time frame. Economically feasible controlled fusion and advanced solar energy power systems are still a long way in the future: "If nuclear power is to have a long-term future, it must be with breeder reactors."

6. MATERIALS

"The health of materials processing and manufacturing technology in the United States is arousing concern [especially] with respect to foreign competition and trends toward moving basic materials operations overseas to take advantage of richer ores, cheaper energy and labor, and less stringent environmental requirements." The report states that for the United States the quantities of materials required will increase only incrementally, and the kinds of materials required will not change much over the next five to ten years. Because the rapid evolution of new materials that began during World War II is still underway, however, the sources of materials and requirements for them could change markedly after five to ten years. Just as the previous section on energy emphasizes the importance of conservation, this section emphasizes the importance, and likely increase, of conservation, recycling, and substitution of materials, which also conserve energy used in, and lessen pollution resulting from, materials manufacturing. The report finds that crises are not imminent in materials supply.

7. DEMOGRAPHY

The two significant demographic changes affecting science and technology noted in this outlook section of the NAS report are (1) changes in the age structure of the Nation—by 1984 there will be an "unprecedented number of young adults of working age [plus] a significantly higher number of elderly people"—and (2) changes in patterns of net internal migration from metropolitan to nonmetropolitan areas—"If current trends continue, in 1984 central cities, especially in the northern and north-central states, will have a disproportionately larger number of the elderly and improverished." These demographic changes portend changes throughout the socioeconomic structure of the Nation. The impact of these demographic trends on the science and engineering establishment are discussed, in part, in the section on Academic Science and Graduate Education, below.

8. HEALTH OF THE AMERICAN PEOPLE

One of the major trends mentioned in this section is that the U.S. population 65 years old and over is increasing steadily. Consequently, there is likely to be a corresponding increase in demand for health sciences in the near-term future from this effect alone. The report states that although major strides in basic health-related sciences can be expected in the next five years, "Still, we know too little to be able to relieve much of the burden of illness in the near future." Areas discussed in the outlook section which are likely to be subjects of increased research over the next five years include cardiovascular disease; cancer, especially its environmental aspects; behavior and disease, including the behavioral aspects of preventing smoking; smoking and adolescence; research on animals; mental illness; aging due to the rising population of elderly people in the United States; genes and environment; health care delivery; and health-services research.

9. TOXIC SUBSTANCES IN THE ENVIRONMENT

Over the next 5 years, perhaps as many as 1,000 new chemicals will be introduced each year. There are serious gaps in the knowledge of the effects of such chemicals and of how to deal with existing toxic chemical problems, such as chemical waste disposal sites and the accumulation of persistent chemicals, like PCB, in lakes and streams. The anticipated increase in the use of coal for power generation, mentioned above, likely will increase toxic substances in the environment in spite of power plant pollution controls. Over the next five years continuing efforts will be required to neutralize such wastes. Because no safe 'threshold level' "has yet been reliably demonstrated for any carcinogen," there is increasing interest in quantitative risk-benefit assessment to evaluate the risks and benefits of individual chemicals: "Are they vitally significant (and worth a significant risk) or trivial (and not worth even a minor risk)?" There will be increased efforts to evolve better risk-benefit assessment methods over the next 5 years.

10. ACADEMIC SCIENCE AND GRADUATE EDUCATION

The major universities of the United States are vital to the programs of U.S. science due to their role in educating young scientists and engineers and in conducting more than half of the Nation's basic scientific research. The scientific momentum of the past will carry these universities through the next five years, but more stringent financial conditions, declining undergraduate enrollments, sharp reduction in the number of new faculty positions, and federally imposed administrative requirements will make this period one of adjustment for universities and academic science. Because of a decline of students and the resulting relative over-supply of existing faculty, the number of specialized research centers associated with universities may increase. The years immediately ahead will be "a time of emphasis on frugality within academic science." The balancing of the universities' administrative burden associated with obtaining Federal funds and the Government's requirements for accountability likely will receive increased attention over the next five years, as will efforts toward improving the relationship between industry and academic science.

11. INSTITUTIONS FOR INTERNATIONAL COOPERATION

The significant differences, as well as interdependencies, that exist between the nations of the East and West and those of the North and South likely will increase efforts in international technology transfer and collaborative research in the near-term future, mainly though existing organizations. Two specific areas among many mentioned in the science and technology outlook where "institutional inventiveness can make a significant difference are the application of scienec and technology to economic development and the technological aspects of arms control."

In summary, *Science and Technology: A Five Year Outlook* presents a number of futures-oriented analyses of selected aspects of science and technology. Other selected aspects of science and technology will be included in future reports, anticipated to be on a biennial basis.

B. Facing the Future

This report presents the major findings of the OECD Interfutures Project which was undertaken in 1975 to study "the future development of advanced industrial societies in harmony with that of developing countries." The objectives of the project are to conduct future-oriented analyses of:

An assessment of longer-term economic developments and relationships among advanced industrial societies;

An assessment of longer-term developments in the relationship between the advanced industrial societies and the developing countries;

An assessment of potential physical constraints and opportunities related to energy, raw materials, or the environment on future development; and

As assessment of the future evolution of international economic structures and systems in response to growing interdependence.

Although the study includes analyses to evaluate the likelihood of technological breakthroughs, the approach is primarily economic in nature. It does attempt, however, "not to neglect the potential struggles, social conflicts, value changes and institutional developments which are inseparable from them."

A major approach of the study is to develop "global or partial" scenarios to, among other things, throw light on the possible policies of certain actors, particularly governments. The report develop six scenarios based upon a number of basic assumptions. The report's several-page discussion of assumptions is not summarized here due to its complexity; rather, the report's schematic representation of assumptions and scenarios is shown below. The basic assumptions are presented in the left-hand column, the other columns are variants, if any, of the basic assumptions:

Definition of the scenarios (1) (2)

Relations between developed countries	Collegial management				Partial abandonment of free trade between the poles
Internal dynamics of the developed societies	Consensus in favour of high growth	Rapid value changes and moderate growth	Conflicts between social groups and moderate growth		
Trend in relative productivities / North-South relations and relations between LDCs	Convergence			Divergence	
Large growth of North-South economic exchanges	A	B1	B2	B3	
Accentuation of divisions between North and South				C	
Partial fragmentation of the South following regional alignments with the developed country poles					D

(1) The fourth dimension concerning the internal dynamics of the various groups of developing societies has mainly been taken into account at the level of the regional analyses incorporated in the scenarios.

(2) To avoid having to repeat the letters, these scenarios are sometimes referred to in the text by the following code names :

A = high-growth scenario; B1 = new-growth scenario; B2 = convergent-moderate-growth scenario; B3 = divergent-moderate-growth scenario; C = North-South rift scenario; and D = protectionist scenario.

Useful though they may be, these code names do not satisfactorily sum up the assumptions underlying the scenarios.

Source: Organization for Economic Cooperation and Development. Facing the Future. Paris, OECD, 1979. p. 86.

The six scenarios are summarized in the report as follows:[39]

Scenario A.—Collegial management and conflicts in the developed countries; increased free trade; increasing Third World participation in world economic exchanges, but varying as between developing countries; sustained economic growth in the developed countries, but no rapid change in values. Relative productivities in OECD countries are assumed to converge.

Scenarios B1, B2, B3.—Identical assumptions as to the nature of relations between developed countries, between developing countries and between the two groups. On the other hand, the developed economies will experience only moderate growth with differences according to the three alternative scenarios. In B1, value changes are rapid and there will be a consensus on the slowdown in growth, since it will be accomplished by a change in the content of "social output" (in the broadest sense of the term). In the other two alternatives, however, there is no significant, unanimously accepted change in values and the slowdown in growth is due to more structural adjustment difficulties at national and international levels than to conscious resolve as in B1. Whereas the B2 alternative supposes convergence of relative productivities, B3 assumes divergence linked to social and institutional disparities between the various developed countries.

Scenario C.—This was introduced in order to analyse the implications of a North-South confrontation. It supposes the implementation of "delinking" strategies by a majority of developing countries, collegial management by the countries of the North with increased liberalisation of their trade, slower growth without any change in values in those countries, and no convergence of productivities because the main OECD zones would be variously affected by the North-South break.

Scenario D.—Break-up of the developed-country group and mounting protectionism with the emergence of zones of influence centered around three poles, the United States, the European Economic Community and Japan. These zones will include regional groups (on a continental scale) of developing countries; trade and capital flows will develop preferentially within those zones. These assumptions are coupled with that of slower growth due in part to the destabilisation of trade flows. Non-convergence of productivities is due here to the differing impact of the break-up process on the main OECD zones.

The report's "prospective analysis" of the four major study areas identified above, based upon the framework of the alternative scenarios, produced a number of conclusions and recommendations which are discussed in the following paragraphs.

The study identifies four critical issue areas that warrant the attention of governments. These are:

The energy transition from petroleum to nuclear power and coal plus the need for energy conservation;

The search by developed countries for national policies adapted to evolving values and social demands, the objectives of sustained, noninflationary growth with full employment, and structural change;

Efforts among the developed nations to assist in the development of the Third World; and

New forms of international cooperation.

While not attempting to be exhaustive, the report suggests a few of the possible policy approaches for illustrative purposes only. The recommendations may be summarized as follows:

1. Avoiding or overcoming transition problems involving natural resources and the environment. "Nothing is more important than forceful energy policies," but strategies also are necessary in other fields like fundamental research in climate, non-energy mineral resources, and soil conservation policies.

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[39] Organization for Economic Cooperation and Development. Facing the Future. Paris. OECD, 1979. p. 85, 87.

2. Conducting the change in the industrial societies. Possible approaches include better coordination of counter-cyclical economic policies among the major OECD countries, disassociating income policies from the functioning of the labor market, obtaining more information about factors underlying structural changes, reconsidering the efficiency of the welfare state, giving enterprises the means to change to new activities, and redistributing responsibilities between central, regional, and local levels.

3. Facilitating the development of the Third World, including improved access to medium- and long-term loans for Third World countries; adoption of measures to improve the effectiveness of aid; a policy for industrial development and technology; and actions concerning commodities, especially raw materials.

4. Managing global interdependence. This would involve reshaping the administrative organization of each developed nation to take account of increasing interdependence, generally reviewing the present workings of intergovernmental organizations, improving the organizational framework for international trade, and establishment by petroleum-producing and petroleum-consuming countries of a framework for ensuring a smooth transition to the post-petroleum era for both producer and consumer nations.

In summary, *Facing the Future* presents a number of coordinated, mainly economic, policy options for governments. These options are based upon several scenarios of possible alternative futures having specific reference to the problems and interdependencies of the industrialized (mainly OECD) nations and the developing countries of the world.

C. Global 2000 Study

The *Global 2000 Report to the President* was undertaken by the Council on Environmental Quality in the Executive Office of the President and the Department of State in cooperation with other U.S. Government agencies,[40] at President Carter's direction to:

> . . . make a one-year study of the probable changes in the world's population, natural resources, and environment through the end of the century [to] serve as the foundation of our longer-term planning. . . .

The basic plan for the study was to identify, with guidance from the cooperating Federal agencies, the long-term global models and tools currently used by these agencies and, with the aid of unifying assumptions, to use these models and tools together as a single, internally consistent system. Each of the participating agencies was asked to develop certain projected trends in their mission areas. The choice of the models and tools to be used was left primarily to the agencies, but with the understanding that the results were to be (1) global, (2) long-term, and (3) based on models and tools normally used by the agencies for similar work.

The study built upon the work of a number of important previous

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[40] Including the Environmental Protection Agency, National Science Foundation, National Oceanic and Atmospheric Administration, Agency for International Development, Bureau of the Census, Central Intelligence Agency, Defense Civil Preparedness Agency, Department of Agriculture, Department of Energy, Department of the Interior, National Aeronautics and Space Administration, and Office of Science and Technology Policy.

U.S. Government-sponsored efforts. The work of the following organizations and commissions were found to be particularly important:

National Commission on Supplies and Shortages (1975)
Advisory Committee on National Growth Policy Processes (1975)
National Growth Reports Staff (1972)
National Commission on Materials Policy (1970)
Commission on Population Growth and the American Future (1970)
National Goals Research Staff (1970)
Public Land Law Review Commission (1965)
President's Commission on National Goals (1960)
Outdoor Recreation Resources Review Commission (1958)
President's Materials Policy ("Paley") Commission (1951)
National Resources Planning Board (1939)

It was found that the earlier of these studies viewed population, resources, and environment primarily as unrelated short-term, national (or even regional or local) topics. Only in the most recent studies were the interrelated, global, and long-term aspects of these issues brought increasingly into focus. The report, however, states that it is the first U.S. Government study to address all three topics from a relatively long-term, global perspective. The study also attempts to emphasize "interconnections and feedback" among the various analytical factors, but in this regard, as stated in the report, it was only partially successful.

The study plan also called for a comparison of the results of the Government's projections with the results of other recent global studies. Since the early 1970's, when the Club of Rome sponsored the first global model to examine longer-term trends involving population, resources, and the environment (the "limits to growth model"), there have been several additional efforts to develop internally consistent global models from a variety of different perspectives. A number of global models now exist, and more are under development. The report examines five such models and compares their results and structures with the Government's global model developed as part of this project.

Volume 1 of the report sets forth its principal findings, which are summarized in the following paragraphs.

The picture of the world in the year 2000 that emerges from the projections looks, on the surface, much like the world of today: no major disasters are expected to alter the appearance of the world significantly over the next two decades. But below the surface there are many important changes. A few of the highlights are as follows: [41]

> Rapid growth in world population will hardly have altered by 2000. The world's population will grow from 4 billion in 1975 to 6.35 billion in 2000, an increase of more than 50 percent. . . . In terms of sheer numbers, population will be growing faster in 2000 than it is today, with 100 million people added each year compared with 75 million in 1975. Ninety percent of this growth will occur in the poorest countries.
>
> . . . the gross national product per capita in most LDCs remains low. . . . The large existing gap between the rich and poor nations widens.

[41] The Global 2000 Report to the President, vol. 1, pp. 1–3.

World food production is projected to increase 90 percent over the 30 years from 1970 to 2000. . . . The bulk of that increase goes to countries that already have relatively high per capita food consumption. . . .

Arable land will increase only 4 percent by 2000, so that most of the increased output of food will have come from higher yields. Most of the elements that now contribute to higher yields . . . depend heavily on oil and gas.

During the 1990s world oil production will approach geological estimates of maximum production capacity, even with rapidly increasing petroleum prices. . . . With the expected price increases, many less developed countries will have increasing difficulties meeting energy needs. . . . Needs for fuelwood will exceed available supplies by about 25 percent before the turn of the century.

While the world's finite fuel resources . . . are theoretically sufficient for centuries, they are not evenly distributed; they pose difficult economic and environmental problems; and they vary greatly in their amenability to exploitation and use.

Nonfuel mineral resources generally appear sufficient to meet projected demands through 2000. . . .

Regional water shortages will become more severe. In the 1970–2000 period population growth alone will cause requirements for water to double in nearly half the world. . . .

Significant losses of world forests will continue over the next 20 years as demand for forest products and fuelwood increases. . . .

Serious deterioration of agricultural soils will occur worldwide . . . and the spread of desert-like conditions is likely to accelerate.

Atmospheric concentrations of carbon dioxide and ozone-depleting chemicals are expected to increase at rates that could alter the world's climate and upper atmospheres significantly by 2050. Acid rain from increased combustion of fossil fuels (especially coal) threatens damage to lakes, soils, and crops. Radioactive and other hazardous materials present health and safety problems in increasing numbers of countries.

Extinctions of plant and animal species will increase dramatically . . . especially in tropical forests.

The future depicted by the U.S. Government projections, briefly outlined above, may actually understate the impending problems. . . .

The conclusions of the Global 2000 Study revolve around "the problems of preserving the carrying capacity of the earth and sustaining the possibility of a decent life for the human beings that inhabit it . . ." These problems are characterized as being "enormous and close upon us." [42] The study also concludes, among other things, that the "needed changes go far beyond the capability and responsibility of this or any other single nation. An era of unprecedented cooperation and commitment is essential." [43]

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[42] Ibid., p. 3.
[43] Ibid., p. 4.

In summary, the Global 2000 Study is a comprehensive analysis by the U.S. Government of factors involved in global population, natural resources, and environmental trends through the year 2000. The study makes use of a number of existing governmental studies and models. It has taken a first step toward increased linkages and improved consistency within the Government's present "global model" which consists of the many different tools and models currently in use by U.S. departments and agencies. The report itself is a first step toward a basis for longer term and more comprehensive governmental planning in these areas.

D. The Europe Plus Thirty Report

This study was undertaken by the Commission of European Communities, an organization amalgamated in 1967 from the individual Commissions, or operating bodies, of the European Economic Community, the European Coal and Steel Community, and Euratom. The report's central purpose is to "help the power centres of the European Communities to make wise decisions in a largely but now wholly uncontrollable world" by establishing a permanent organization of about 75 professionals, to be called "Europe Plus Thirty," to "foresee crises, to forecast about the underlying causes of inflation, and generally to reduce the uncertainty of the future."

The report deals with four major areas:

Existing capacity and processes within the European Community to do futures research;

The "fields of forecasting" required by the European Community;

The potential role of technology assessment in serving the European Community; and

The outlines of the proposed organization, "Europe Plus Thirty."

Each of these major points of the report are discussed in the following paragraphs.

1. CAPACITY AND PROCESS

The report recommends that the proposed Europe Plus Thirty organization do, or integrate, all forecasting studies done by the Commission's subunits which have time horizons beyond 4 years. The report was unable to make any generalization about the existing forecastinng capacity and pattern in the European Communities at the time of the study, but concluded that the Community "does indeed stand in need of a long-term forecasting capacity . . ."

The report discusses 26 specific types of forecasting techniques or methods in common use today and concludes that "some of these are held to be useful, some virtually useless, some interesting but dangerous, and many in between." The report points up the importance of an effective linkage between the forecasters and the policy- or decisionmakers using the forecasts:

> The most fruitful use of forecasting requires a continuous dialogue between the forecasters and their clients. Without direct access for the forecaster to the decisionmaker himself, the whole operation is bound to be accident-prone.

2. FIELDS OF FORECASTING

The following 16 fields were determined to be important areas of analysis for inclusion in the integrated futures research system envisioned as Europe Plus Thirty:

Climate
Population
Agriculture, Fisheries, and Forestry
Health
Social Structures and Values
Education
Science and Technology
Industry
Energy
Material Resources
Environment
Transport
Communications
Economy and Finance
Defense and Disarmament
Politics and Institutions

3. TECHNOLOGY ASSESSMENT

The report suggests that a technology assessment capability be incorporated into the overall forecasting and futures research capabilities of the proposed Europe Plus Thirty system in order that the system be fully able to evaluate in advance the potential, unintended and indirect, social, economic, environmental, and other effects of technologies, as well as their primary and intended effects.

4. EUROPE PLUS THIRTY

The *Europe Plus Thirty Report* concludes with a recommendation that an organization to be called Europe Plus Thirty be created to carry out, on a permanent basis, the futures research and forecasting and technology assessment tasks that the report holds as being required by the European Community. The report suggests an organization of preferably about 75 professionals composed of specialists in the several fields mentioned above plus some "generalists." This recommendation reflects the view that the European Community can be most effectively provided with futures-oriented information and services by a permanent and adequately staffed and funded organization having effective linkages with European Community decisionmakers.

In summary, the *Europe Plus Thirty Report* is a proposal for the creation of an effective and permanent futures research and forecasting and technology assessment organization to serve the policymakers and institutions of the European Community. That organization would conduct integrated futures-oriented analyses and assessments across many fields, provide reports on specific topics, and interact effectively with European policymakers.

E. Other Recent Science and Technology Outlook Reports

Several other recent science and technology outlook reports or futures-oriented reports having a science and technology outlook component (in addition to the four discussed above in some detail) have recently been published, both in the United States and abroad. Without attempting to be comprehensive, but rather to indicate the "flavor" of these recent efforts, the following brief listing is provided:

Kahn, Herman. World Economic Development: 1979 and Beyond. Boulder, Colorado, Westview Press, 1979. 519 p.

Edison Electric Institute. Economic Growth in the Future: The Growth Debate in National and Global Perspective. New York, McGraw-Hill Book Company, 1976. 423 p.

Committee on Scientific and Technological Policy. Science and Technology in the New Socio-Economic Context. Paris, Organization for Economic Cooperation and Development, 1979.

Study Group on Structural Adjustment: Report. Canberra, Commonwealth of Australia, 1979.

Netherlands Scientific Council for Government Policy. The Next Twenty-five Years. The Hague, 1978. 197 p.

Royal Swedish Academy of Engineering Sciences. Technical Capability and Industrial Competence—A Comparative Study of Sweden's Future Competitiveness. Sweden, 1979.

Cabinet Office. Advisory Council for Applied Research and Development. Industrial Innovation. United Kingdom, 1978.

Wilson Committee. The Financing of Small Firms. (Interim Report) United Kingdom, 1979.

General Scheme of the Research and Technology Policy for Small and Medium-Sized Firms. Federal Republic of Germany.

VII. Analysis and Outlook

This study is an attempt to set forth a preliminary structure for a comprehensive Science and Technology Outlook, particularly as science and technology relate to economic change. The approach is fivefold. It is to:

1. Examine the systemic factors involved in the Nation's scientific-techno-economic-socio-political system. Twenty-two factors were discussed in Chapter II, from science and technology education to societal factors impacting on science and technology.
2. Investigate the total "environment" in which the national science and technology system operates. This environment is the world. Fourteen major problem areas were identified in Chapter III, from the world food-population balance to science and technology itself as a major area of problems and opportunities.
3. Identify some emerging technological developments which seem likely to be particularly important in the near-term future. Ten emerging technological developments were identified in Chapter IV as being appropriate for in-depth technological forecasts and impact assessments. Many additional emerging technological developments could be identified.
4. Review basic assumptions, an often neglected task in policy

analysis. Three alternative scenarios, each incorporating different sets of basic assumptions, were discussed in the form of narrative statements in Chapter V.

5. Analyze the above preliminary findings and suggest policy alternatives.

It seems that a comprehensive Science and Technology Outlook should deal with at least the above five major analytical areas. The following pages of this chapter present an attempt to analyze the preliminary findings of this study and set forth same possible policy alternatives suggested by the analysis. A comprehensive and thorough Science and Technology Outlook along the lines suggested above could be an important tool for future Government policy formulation.

A. Analysis and Outlook

1. THE SCIENTIFIC-TECHNO-ECONOMIC-SOCIO-POLITICAL SYSTEM

The "system" has many emerging problem areas of likely concern to the Congress. Briefly these (discussed above in Chapter II) include:

Maintaining the vitality of science and technology education and continuing to support (particularly university) basic research;

Determining the proper balance, and maintaining that balance through the Federal R&D budget process, between Federal R&D support of defense, energy, space, and health programs and other civilian R&D programs;

Determining the proper role of the Nation's Federal and industrial laboratories, particularly in regard to technological innovation;

Dealing with the apparent shift from long-range, fundamental industrial R&D and innovation to short-range, low-risk, "defensive," incremental industrial R&D and innovation;

Dealing with increasing international techno-economic competitiveness (particularly with Japan and Western Europe) in high-technology trade;

Evaluating whether there is a need to redefine the Nation's goals to include an explicit goal of techno-economic security;

Responding positively and in a timely manner to apparently increasing pressures for public participation in science and technology policy-making activities; and

Simultaneously responding effectively to literally scores or even hundreds of other major emerging science and technology issues similar to those discussed in Chapter II.

All of the above emerging problems in the science and technology system suggest that perhaps the major science and technology problem area in the future may be whether or not to further develop the Federal science and technology policy and management structure in the executive branch as discussed above in Section E of Chapter II. That might involve the establishment of a new and permanent science and technology coordination and management organization of perhaps several hundred persons, with some kind of crosscutting authority to require science and technology related actions throughout the operating levels of the Federal departments and agencies. Without some type of overall presidential-level science and technology policy management capability, the other science and technology system problems discussed above may not be dealt with comprehensively, continuously, and in a coordinated fashion in the years ahead. As discussed in the preceding chapter, the *Europe Plus Thirty Report* proposes a similar permanent organization for the Commission of European Communities.

2. MAJOR WORLD PROBLEM AREAS

The study identified the following 14 major world problem areas (that is, the world "environment") to which the national science and technology system will be called upon to respond frequently in the years ahead. These areas are:

- World population growth and aging populations
- Ford: agricultural production and distribution
- Foreign affairs and military security
- Techno-economic security and viability
- Energy
- Environment
- Non-energy resources and materials
- Political and societal tensions and breakdowns
- Health and biosciences
- Human settlements
- Transportation and telecommunications
- Education
- Governance
- Science and technology imperatives and projects

The National Academy of Sciences' report, *Science and Technology: A Five-Year Outlook*, addressed a similar list of selective science and technology subjects in some depth.

It is beyond the scope of this analysis to suggest which of these potential problem areas will in fact become the critical areas in public policy in the years ahead—although the world population-food balance problem and the impending permanent decrease in the natural supply of the world's petroleum, for example, would certainly rank high as potential crises. What does appear to be certain is that, without increased analytical capabilities in foresight, the Nation is likely to stumble from one crisis situation to another and react to emerging problems only on a shortsighted and incremental basis. The institutionalization of foresight information collection and analysis seems to be developing reasonably well today. The next step would appear to be to develop adequate linkages between these foresight capabilities and the congressional and executive branch policy and decisionmakers who will have to cope with these emerging problems by formulating timely policy solutions.

Unless policy foresight and linkage capabilities are developed and institutionalized fairly rapidly, some of the potential world problems identified in this analysis will occur without adequate warnings to, or at least without belief in those warnings by, decisionmakers, and the political responses to these problems probably will be inadequate.

The Congress has begun to formally incorporate foresight functions into its operations. For example, under the House of Representatives' Committee Reform Amendments of 1974:[42]

> Each standing committee (other than the Committee on Appropriations and the Committee on the Budget) shall . . . on a continuing basis undertake future research and forecasting on matters within the jurisdiction of that committee . . .

In the future, particularly if the executive branch enhances its science and technology policy management and policy foresight capabilities along the lines of the OSTP–NSF–NAS Five-Year Outlook and the CEQ *Global 2000 Study*, Congress may need to increase its own science and technology policy development, coordination, and foresight capabilities to include: (1) Increased coordination among the science and technology committees in each house and between the two houses and (2) improved interactions between these science and technology committees and other committees who jurisdictions impact on, or are impacted on by, science and technology.[43]

3. EMERGING TECHNOLOGICAL DEVELOPMENTS

Scientific, technological, and techno-economic developments have an imperative or dynamic of their own, as well as being responsive to societal needs. Some emerging technological developments were identified in Chapter IV. These and many other technological developments probably should be tracked on a continuing basis in order to (1) provide information to develop technology forecasts of these technologies and to assess their likely societal impacts and (2) promote those that appear to be beneficial and ameliorate the impacts of those that appear to be detrimental.

Probably the most effective political response to dealing with the potential problems and opportunities associated with emerging technological developments would be to institutionalize at the national level a policy foresight capability with linkages to policymakers, as addressed immediately above in the discussion of major world problem area. A comprehensive policy foresight capability probably would include a technology forecasting activity to prepare forecasts of emerging technologies like those discussed in Chapter IV.

4. BASIC ASSUMPTIONS

Basic assumptions about the Nation's future should be challenged from time to time. It is possible that within 30 years major changes will have rapidly occurred in either (1) the basic values of many Americans and other world citizens, thereby causing significant societal changes that will impact on science and technology, or in (2) some major physical, economic, political, or other subsystem of the world system to such an extent that a major discontinuity will occur. Only if it is assumed that basic societal parameters will change slowly

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[42] H. Res. 988, adopted by the House on Oct. 8, 1974.

[43] For discussions of congressional foresight activities, see, Renfro, William. Foresight: Congress Looks to the Future. CRS Issue Brief 77007; Renfro, William. Forecasting and Futures Research in Congress: Background and Prospects. CRS Report 77–169 SP. Washington, Library of Congress, Aug. 24, 1977. 55 p.; Renfro, William, Cynthia Huston, and Keith Bea. Foresight in the 95th Congress—First Session. CRS Report 78–18 SP. Washington, Library of Congress, Jan. 19, 1978. 24 p, and Little, Dennis L. Implementing the House Foresight Provision. Sept. 18, 1979. 26 p.

or not at all can alternative scenarios, like those developed in Chapter V, be ignored. As discussed above, the OECD report, Facing the Future, incorporated basic assumptions relevant to the future of the industrialized and developing nations into its six scenarios of alternative futures.

The outlook for science and technology hinges in significant part on major societal trends. Examples of trends are presented in the three scenarios discussed above and in the discussions of societal and environmental factors in Chapter II. It is unclear now which trends will predominate in the future, but science and technology policymakers must continue to be aware of the possibility of significant societal changes occurring in the years ahead.

B. Outlook and Options

Taking basic assumptions first—the extrapolative scenario now seems to be the most likely and most preferable of the three presented in this analysis, although it includes significant existing and emerging problems. Hence, national science and technology policy alternatives are likely to be developed around this basic scenario or a similar one, either implicitly or explicitly.

One paragraph of the extrapolative scenario is reproduced here because it bears significantly on the Science and Technology Outlook:

> Of the factors discussed here, only the application of science and technology, particularly Government directed science and industrial science and technology, will have both the potential for being amenable to effective national management and creating the productivity required to offset the negative factors which appear to be considerably less amenable to management.

If this paragraph catches the likely significance of science and technology in the future, the national science and technology system probably should be maintained and improved by addressing major systemic problem areas like those listed above in Section A.1 of this chapter, and discussed at length in Chapter II.

Assuming the general validity of the extrapolative scenario, the national science and technology system may be called upon to contribute, in a global context, to the solution of most of the major world problem areas discussed in Chapter III above, and listed in Section A.2 of this chapter. In the activistic, dynamic society envisioned in the extrapolative scenario, none of these 14 major world problem areas is likely to be ignored and the following ones are likely to be particularly emphasized:

World population growth and aging populations
Food: Agricultural production and distribution
Foreign affairs and military security
Techno-economic security and viability
Energy
Health and biosciences

Likewise, under an extrapolative scenario, all of the representative emerging technological developments discussed in chapter IV, and many more, are likely to receive increasing attention and programmatic support from both industry and Government. These are, for ease of reference:

Birth control
Food: Aquaculture

Health: Combating future cancers
Biosciences and bioethics: DNA
Microelectronics: Computers and telecommunications
Transportation: Short-hop STOL airlines
Technology-abetted political participatory systems
Energy: Oil shale
Energy: Fusion
Space colonization

Finally, under an extrapolative scenario, two organizational policy alternatives are likely to receive increasing attention at the Federal policymaking level, These are:

Further development of the Federal science and technology policy and management structure; and

Further development, and perhaps institutionalization, of the Nation's analytical foresight capabilities and of effective linkages between those capabilities and science and technology policymakers.

By way of contrast, should a changing values scenario more accurately represent the likely future than an extrapolative scenario, the Science and Technology Outlook would be different from that described in the above paragraphs. For example, of the several major systemic problem areas listed above in Section A.1 of this chapter, the following probably would not receive priority attention from science and technology policymakers:

Dealing with the apparent shift from long-range, fundamental industrial R&D and innovation to short-range, low-risk, "defensive," incremental industrial R&D and innovation;

Dealing with increasing international techno-economic competitiveness (particularly with Japan and western European) in high-technology trade; and

Evaluating whether there is a need to redefine the Nation's goals to include an explicit goal of techno-economic security.

On the other hand, another factor might receive greater emphasis than under the extrapolative scenario:

Responding positively and in a timely manner to apparently increasing pressures for public participation in science and technology policymaking activities.

If a changing values scenario were more likely than an extrapolative scenario, the national science and technology system probably would be called upon to respond to major world problem areas in a different way than under an extrapolative scenario. For example, of the 14 major world problem areas listed above in section A.2 of this chapter, the following likely would be emphasized:

World population growth and aging populations [44a]
Food: agricultural production and distribution [44a]
Environment
Political and societal tensions and breakdowns
Health and biosciences [44a]
Human settlements
Education

[44a] Also likely to be emphasized under an extrapolative scenario as discussed above.

Finally, under a changing values scenario, some of the representative emerging technological developments discussed in Chapter IV, and above as likely to be supported under an extrapolative scenario, might not be well supported, like the following:

Biosciences and bioethics: DNA
Microelectronics: Computers and telecommunications
Energy: Oil shale
Energy: Fusion
Space colonization

A recent paper [44b] suggests that some major changes in societal values—changes which are particularly likely to affect society's future relationship to science and technology—are already occurring. For example:

For three hundred years science and technology—the systematic organization of knowledge and the knowledgeable organization of systems—have been driving society. But in the 1970's, the worm has turned: society is starting to take charge of science and technology.

The implications of this trend—for the meeting of human needs, for the security of peoples, for the very nature of "growth" and "development," for scientific discovery and technological innovation themselves, and above all for social and political management—are enormous. Non-scientists and non-engineers will have to learn enough about science and technology to substitute a social wisdom for a guidance system based on the "inner logic" of science and technology themselves.

If such major societal value changes are occurring, the many systemic and other factors related to science and technology are likely to be affected in ways significantly different than would be the case under the extrapolative scenario, perhaps in ways such as suggested above.

Related to both the extrapolative scenario and the changing values scenario are the findings of a recent study of future national and international problem areas.[45] This study explores possible changes in the existing science and technology paradigm [46] itself. Such changes would be manifested in the very way science and technology, and science and technology policymaking, are carried out. One set of emerging changes in the existing science and technology paradigm can be represented by the following two columns in which currently dominant science and the technology characteristics, like those in the left-hand column, are beginning to be complemented or balanced by emerging characteristics like those shown in the right-hand column.[47]

[44b] Cleveland, Harlan. The Worm Has Turned: Reflections on the Human Assessment of Technology. An Address at the Invitation of The Office of Technology Assessment. Washington, Mar. 21, 1979. 29 p.

[45] SRI International. Assessment of Future National and International Problem Areas. Volume 1. [Prepared for the National Science Foundation.] Washington, U.S. Government Printing Office, 1977. 112 p.

[46] A paradigm is "A set of relationships like a model, but more abstract and less quantitatively defined than a model. Thomas Kuhn defines paradigms as 'universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners.' Ayres defines it as 'a structured set of axioms, assumptions, concepts, hypotheses, models, and theories, e.g., Newtonian physics or Marxist economics.' " From Kuhn, Thomas S. The Structure of Scientific Revolutions. Chicago, The University of Chicago Press, 1962: x; and Ayres, Robert U. Technological Forecasting and Long-Range Planning. New York, McGraw-Hill Book Company, 1969: xiii. In U.S. Congress. House. Committee on Science and Technology. Subcommittee on Science, Research, and Technology. Science Policy: A Working Glossary [Fourth Edition—1978]. Committee Print, 95th Congress, 2d session. Washington, U.S. Government Printing Office, 1978: 50.

[47] SRI International, op. cit., p. 58.

Reductionist explanations (e.g., physiological processes in terms of elemental physical and chemical interactions).	*Holistic explanations* (e.g., physiological process in terms of their function in the life pattern of the whole organism).
Objective engrossment (i.e., science built on data from the physical senses and their technological extensions, e.g., microscope, spectrograph).	*Subjective exploration* (impelled by a basic assumption that there are common inner perceptions about which men can agree, as well as commonly experienced sensory data).
Prediction and control emphasis, knowledge valued for its technology-creating potential; implies a manipulative and exploitative ethic.	*Emphasis on guiding human and social development;* knowledge valued for the insight it gives into man's purposes and potentialities.
Deterministic models (both causal and stochastic models).	*Teleological models* (e.g., goal-impelled systems).
Value-inattentive (e.g., physics, astronomy, biochemistry).	*Value-focused* (e.g., the health sciences, political economics clinical psychology (Lowe, 1965).
Efficient technology.	*"Appropriate" technology.*
Basic and applied science, the former serving the latter, and the latter leading to development of control-oriented technology.	*Policy science,* directed to understanding and monitoring the course of critical human relations—ecological, political, and social as well as economic—with a view to guiding policy (Kuhn, 1970).

If the science and technology paradigm shift, noted in the above report, were to continue unabated in the near-term future, a scenario based upon the paradigm shift would become appropriate for the consideration of science and technology policymakers.

A discontinuity scenario, probably the least likely and most undesirable of the three scenarios discussed in this analysis, would affect the several factors involved in a Science and Technology Outlook to a significantly greater extent than would be the case under either of the other two scenarios. The effects of a discontinuity scenario on the Science and Technology Outlook will not be discussed here except to note that, to the extent that foresight and linkage capabilities are perfected and instituted in the legislative and executive branches and also perhaps in the private sector, the disruptive effects of a major world or national discontinuity on science, technology, and the national economy could be significantly ameliorated.

The world system is extremely complex and its future is largely unknown. Nevertheless, the concept of a Science and Technology Outlook begins with the premise that the future is not unknowable. Several trends, events, questions, and issues in science and technology relevant to the functioning of the national economy in its global context have been identified and examined in this report. To investigate these factors comprehensively, thoroughly, and continuously probably would require the institutionalization of the Science and Technology Outlook at the Federal policymaking level.

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