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TECHNOLOGY, ECONOMIC GROWTH, AND INTERNATIONAL COMPETITIVENESS

A REPORT

PREPARED FOR THE USE OF THE

SUBCOMMITTEE ON ECONOMIC GROWTH

OF THE

JOINT ECONOMIC COMMITTEE
CONGRESS OF THE UNITED STATES

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LETTERS OF TRANSMITTAL

JULY 3, 1975.

To the members of the Joint Economic Committee:

Transmitted herewith for the use of the Members of the Joint Economic Committee and other Members of Congress is a study entitled "Technology, Economic Growth, and International Competitiveness," prepared for the Subcommittee on Economic Growth. The study examines the process of research, technology development and innovation in industry and the efficacy of Federal policies to foster their progress.

HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee.

JULY 2, 1975.

Hon. HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee,
U.S. Congress, Washington, D.C.

DEAR MR. CHAIRMAN: Transmitted herewith is a study entitled "Technology, Economic Growth, and International Competitiveness," prepared by Professor Robert Gilpin of Princeton University under contract to the Subcommittee on Economic Growth. The study provides a timely basis for testimony in upcoming hearings of the Subcommittee.

Professor Gilpin examines the thesis that the United States has lagged in recent years in the development and application of new civilian technology because, among other things, of a faulty conception of the innovative process by Federal policymakers, an inappropriate allocation of Federal R & D funds, and a lack of adequate communication and coordination between research scientists and those in charge of industrial applications. The experiences of other industrial countries also are brought to bear on the issue.

The Subcommittee on Economic Growth is very grateful for Professor Gilpin's contribution to its investigation. The views expressed in this study, of course, are those of its author and not necessarily those of the Subcommittee, any of its individual members, or the Joint Economic Committee staff.

LLOYD M. BENTSEN,
Chairman, Subcommittee on Economic Growth.

CONTENTS

I. INTRODUCTION: TECHNOLOGY AND THE ECONOMY

The argument of this report is that technological innovation in the civilian industrial sector of our economy is at a critical point. Partially due to policies pursued (or, rather, not pursued) by government and industry, and partially due to developments beyond our control, America's once unchallenged scientific and technological superiority has deteriorated. The implications of this reversal are of immense importance for both our domestic welfare and our international position. As a consequence, there is a pressing need to initiate the necessary policies and create the policy mechanism to stimulate the technological innovations and industrial productivity required to help meet international economic competition, stimulate economic growth, and solve our domestic problems. In order to know what policies and institutions are needed, there are several things we must do. First, we must take stock of where we are now. Second, we must understand the nature of the R and D enterprise in order to appreciate what government can and cannot do. And, third, we must formulate appropriate policies and the institutional mechanism for carrying out those policies in the most effective and expeditious manner.[1] However, it must be appreciated that the problem we face in the area of technological innovation is a profound one and that there are no easy answers.

As remarkable as it may now appear, until a very few years ago economists tended to overlook the economic significance of technological innovation. Students of domestic economics explained economic growth in terms of the quantitative growth of inputs of labor and capital. The so-called "residual" of unexplained growth was labeled "technical progress," and left essentially at that (Denison 1962; OECD, 1974). The patterns of international trade and competitiveness were explained by resource endowments or comparative advantages which were considered static and unchanging, at least in theory.

The importance of technological innovation for economic growth gained recognition when Robert Solow in 1957 published an article which showed that considerably more than half of the increase in American productivity had been due to scientific and engineering advances, to industrial improvements, and to know-how of management methods and the education of labor. As a consequence of this pioneering study and subsequent researchers of other economists, economists appreciate today that the foremost input to economic growth is the advancement and utilization of knowledge. The pre-

[1] Originally, this writer intended to include agricultural as well as industrial research. Although the American system for agricultural research is the envy of the world, it is not free from criticism. These criticisms and recommendations for reforms were contained in an excellent 1973 report of the National Academy of Sciences. *Report of the Committee Advisory to the U.S. Department of Agriculture*, 1973. While this report is not itself free from criticism, it seemed redundant to go over the same ground in the present report. For this reason, agricultural research despite its importance is discussed only peripherally in this report.

vailing attitude of economists has been summarized by Simon Kuznets in the following terms:

> The major capital stock of an industrially advanced nation is not its physical equipment; it is the body of knowledge amassed from tested findings of empirical science and the capacity and training of its population to use this knowledge effectively. One can easily envisage a situation in which technological progress permits output to increase at a high rate without any additions to the stock of capital goods. (Kuznets, 1968, pp. 34–35.)

With respect to international trade, although economists had long appreciated that comparative advantage changed over time due to technological innovation and other changes, economic theory did not (and some would say still does not sufficiently) reflect qualitative factors. International economists until very recently thought in terms of static endowments and quantities of land, labor, or capital. But attitudes began to change when Leontieff showed in the 1950's that U.S. exports were labor-intensive rather than capital-intensive—the opposite of what conventional theory predicted. This paradox was explained primarily in terms of the skills and high productivity of American labor. Subsequently, Posner, Vernon, and others showed that high-income countries such as the United States have a comparative advantage in the innovation of new products and processes (Vernon, 1966). As a consequence, for advanced countries at least, technological innovation and industrial know-how became recognized as the major determinant of international competitiveness.

The major implication of these findings is that for a country such as the United States, a high priority must be given to industrial and agricultural innovation and the adoption of new technologies. In particular, a high-wage economy such as that of the United States in a world where new knowledge and technological innovations rapidly diffuse to lower-wage economies, must be able to innovate and adopt new technologies with equal rapidity if it is to stay competitive. American firms must in fact run faster and faster merely to stand still. For this reason, the status of industrial innovation and of the national R and D effort must be a central concern of the United States government.

In recognition of this responsibility, the United States government has become the foremost patron of *fundamental or basic research*. The justification of this financial support arises from several factors: It is impossible to predict the outcome of research; the results have general social and economic value; and the public nature and long-term applicability of the results mean that private industry cannot usually capture the benefits of application and therefore has little incentive to support basic research. The government also supports applied R and D relevant to its own areas of responsibility: defense, health, education, public works, etc. Also, it has long accepted the responsibility for *agricultural* research and the diffusion of findings to farmers. And, finally, in a few industrial sectors—aviation, atomic energy, and space among others—the government has financed scientific research and experimental development in the private sector and in public laboratories.

While there are important questions of the appropriate role of government and the effectiveness of its policies in all these areas, the major set of issues facing the United States today relate to the area of *civilian industrial innovation.* What should the government do to increase the productivity and competitiveness of American firms? What can the government do to increase productivity and foster a higher rate of economic growth? What can the government do to ensure that technological advance is socially beneficial? What policies should be pursued to develop technologies which reduce America's dependence upon foreign sources of energy and other potentially scarce resources? These questions are the principal ones which concern us in this report.

By *technological innovation,* this report means "the technical, industrial and commercial steps which lead to the marketing of new and improved manufactured products and to the commercial use of new and improved production processes and equipment." (Pavitt and Walker, 1974, p. 17.) The emphasis of this report is upon innovation of technology as well as upon the diffusion and adoption of innovations by industrial firms. This latter process is also obviously of great economic importance. Many, in fact, of the technologies identified with American technological leadership were first developed abroad. One strength in fact of American industry has been its ability to turn "inventions" of whatever origin into successful innovations (see below). Furthermore, it must be appreciated that innovative activity involves far more than research and exploratory development. At the other end of the spectrum of the innovative process, it involves heavy investment in production facilities and marketing.

The emphasis upon technological innovation and diffusion in this report should not be construed to imply that they are the primary determinants of economic growth, industrial productivity, and trade performance. Other factors are obviously of critical importance: fiscal and monetary policy, capital intensity, industrial organization, the composition of labor skills, exchange rates, commercial policy, and so forth. Nor is this report arguing that the deterioration of our economic position is due primarily to inadequate investment in civilian-related R and D. Other factors such as inadequate capital investment and the over-valuation of the dollar are of equal importance. Certainly, too, the Vietnam War and its impact on the economy (inflation, resource distortion, etc.) have also been of considerable importance. Moreover, the revival of the European and Japanese economies in itself has diminished what once appeared to be an unbreachable "technological gap"; the diffusion of American technology and managerial skills to these economies accelerated their "catching up." In short, the decline of the American economy relative to other industrial economies has been a function of a large number of forces at work both in the American economy itself and in the larger world economy.

Yet, American policies toward technological innovation are an important factor in explaining the present unfortunate situation in which we find ourselves. The assessment of one of America's foremost experts on the economics of technology may serve to make the point:

> 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. Turning to the adequacy of the nation's investment in R & D, there is too little evidence to support a very confident jugdment as to whether or not we are underinvesting in certain types of R & D. 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 R & D seem very high. Additional research is badly needed to determine more adequately the relationship of R & D to economic growth. I have indicated a number of specific areas where work is needed. (Mansfield, 1972, p. 486).

Of equal importance, the reform of government policies toward technological innovation can help overcome our present difficulties. Through improved policies toward civilian R and D, the United States can increase industrial productivity and the development of new products for world markets. While these policies alone cannot solve the problems of lagging economic growth and poor export performance, or our many problems of domestic welfare, they are a necessary ingredient. A complete prescription of how we could resolve the difficult and complex problems we face would require a report many times the size of this one and a genius I do not possess. Therefore, with this understanding of both the inherent limitations of this report and an appreciation of the importance of technological innovation in the larger solution to our problem, let us turn to the condition of the American economy.

II. THE AMERICAN ECONOMY: DECLINE AND RESPONSE

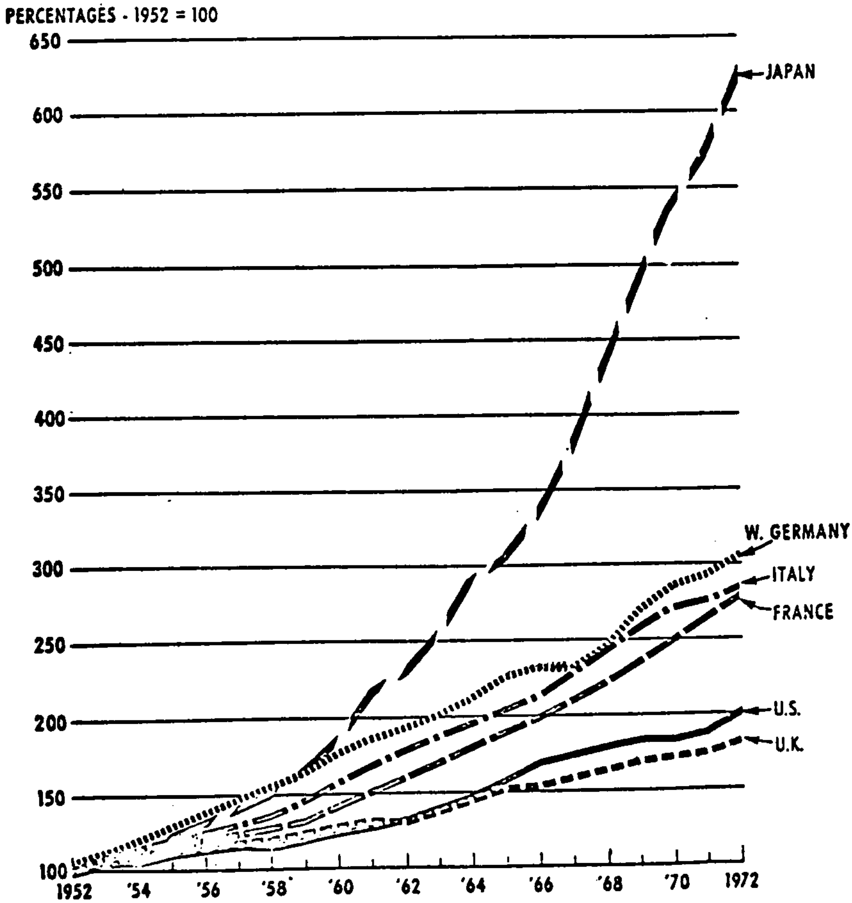
In early 1974, one of America's most distinguished and respected economists, Charles Kindleberger, published an article in which he considered whether or not the American economy was undergoing a climacteric. (Kindleberger, 1974.) Like Great Britain in the latter part of the nineteenth century, the United States was being overtaken and surpassed by more dynamic foreign economies, particulary those of the West Germans and the Japanese. The evidence was mounting, he argued, that the United States was not only falling behind in overall economic growth but in the innovation of new technologies. Like the British, rather than developing new products for world markets, we were trying to hold our own in older areas of technologies—steel, automobile, etc.—and not doing very well at that. This section of the report will first examine the evidence for this relative decline of the American economy and, then, will consider the three alternative responses which are possible for this nation.

The Relative Decline of the American Economy

By the time of President Nixon's announcement of his New Economic Policy in August 1971, a profound shift in the global distribution of economic power had taken place, particulary in the direction of Western Europe and Japan. Throughout the 1950's and 1960's, Western Europe, (excepting Great Britain) and Japan enjoyed higher rates of growth of gross national production than did the United States. (See Figure 1.) Whereas Japan was growing at 13 percent a year and Europe at 7 percent, the United States throughout this period tended to grow at 3 to 4 percent a year. As a result, the United State's share of world GNP had fallen dramatically from nearly 40 percent in 1950 to around 30 percent in 1970 while the Common Market share had risen from 11 percent to nearly 15 percent. European competitiveness also improved; the American share of global exports shrank from 16.7 percent in 1950 to 13.7 percent in 1970, while the Common Market share rose from 15.4 percent to 28.6 percent, of which nearly half was intra-EEC trade.

FIGURE 1

"REAL" GROWTH OF GNP FOR SELECTED COUNTRIES
1952 - 1972



Source: U.S. Department of State, Bureau of Public Affairs, "Economic Growth of OECD Countries, 1962–72," August 1973, p. 11.

Additional evidence for an American climacteric was to be found in the area of technological innovation. National comparisons of innovativeness must be approached with care. Yet, outside the military and aerospace spheres, the evidence suggested to astute observers like Kindleberger that American innovation had become sluggish in commercial technology. In areas where the United States had formerly reigned supreme, such as electronics, automobiles, steel-making, and ship-building—Japanese firms in particular were taking the lead. Japanese entrepreneurship appeared to be more dynamic and creative than its American counterpart. The Japanese also saved more and invested more in their domestic economy. According to a recent U.S. Treasury study, business investment during the period 1960–1973 averaged only 13.6 percent of national output in the United States, compared to 29 percent in Japan, 20 percent in West Germany, 18.2 percent in France, and 17.4 percent in Canada. (*The Wall Street Journal*, May 9, 1975.) These figures support Kindleberger's observation, "that the balance of payments difficulties of the United States [were] due to a slowing down of innovative capacity relative to Europe and, above, all to Japan, and to an increase in spending, relative to income, on the part of business, households, and government." (Kindleberger, 1974, p. 41.)

Furthermore, the composition of American imports and exports reflected her relative decline as an industrial economy (Table 1). After 1967, America's trade surplus began to decline dramatically. By 1971, the United States had a trade deficit. Though American exports in technology-intensive manufactures (capital goods, transportation, scientific instruments, etc.) and in agriculture continued to remain strong, the United States went into severe deficit with respect to fuels, consumer products, and other categories. But even in technology-intensive goods, the rate of export growth declined and that of imports increased. As Table 2 reveals, the United States not only had a declining surplus with Western Europe, it actually had a deficit with Japan. In effect, the American trade position had drastically deteriorated from a $6.1 billion surplus in 1965 to a deficit of about $6.0 billion in 1972.

Among American economists, there were two contrasting sets of explanations for this deterioration of America's trading position. (Boffey, 1971.) On one side of this debate were those economists like Richard Cooper and Robert Solomon who emphasized a number of short-term factors especially the American price level. American goods had become non-competitive because of Vietnam-generated inflation and the apparent inability of the United States to devalue the dollar. This situation had also encouraged American corporations to invest abroad rather than to export. According to this position, the American problem was not economic maturity but particularly an overvalued dollar; it was a cyclical phenomenon. It could be reversed through devaluation and other appropriate policy changes as it was in 1973 when the United States had a trade surplus of $0.5 billion.

TABLE 1.—STRUCTURAL CHANGES IN U.S. MERCHANDISE TRADE,[1] SELECTED YEARS, 1960–71

[Dollar amounts in millions]

Commodity group	1960	1965	1970	1971	Average annual growth in 1960–70 (percent)	Growth in 1971 over 1970 (percent)
Agricultural products:						
Exports	$4,830	$6,229	$7,247	$7,695	3.3	6.1
Imports	3,824	4,082	5,767	5,768	2.9	0
Balance	1,006	2,147	1,480	1,927		
Minerals, fuels, and other raw materials:						
Exports	2,277	2,565	4,504	3,818	6.6	−18.0
Imports	3,985	5,372	7,005	7,910	6.0	12.9
Balance	−1,708	−2,807	−2,501	−4,092		
Not technology-intensive manufactured products:						
Exports	3,573	4,409	6,778	6,262	7.1	−8.0
Imports	4,494	7,350	12,928	14,550	12.4	12.5
Balance	−921	−2,941	−6,150	−8,288		
Technology-intensive manufactured products:						
Exports	9,010	13,030	22,565	24,187	10.0	7.2
Imports	2,359	3,895	12,978	15,898	21.7	22.5
Balance	6,641	9,135	9,587	8,289		
Commodities not classified by kind:						
Exports	718	954	1,496	1,535	7.2	2.6
Imports	401	730	1,274	1,476	14.7	15.8
Balance	317	224	222	59		
All commodities:						
Exports, including reexports	20,608	27,530	43,224	44,137	7.7	2.1
Imports	15,073	21,429	39,952	45,603	11.3	14.1
Balance	5,535	6,101	3,272	−1,465		

[1] The commodity breakdown in this table slightly differs from that presented in Secretary Stans' testimony of July 27, 1971.

Source: U.S. Congress, House, Committee on Science and Astronautics, "Science, Technology, and the Economy," 92d Cong., 2d sess., April 1972, p. 5.

TABLE 2.—TRADE [1] IN TECHNOLOGY—INTENSIVE MANUFACTURED PRODUCTS, BY REGION

[Dollar amounts in millions]

Area	1960	1965	1970	1971	Annual growth in 1960–70 (percent)	Growth in 1971 over 1970 (percent)
Europe:[2]						
U.S. exports	$2,555	$3,708	$7,070	$6,965	9.5	−1.5
U.S. imports	1,363	2,067	4,701	5,373	14.6	14.3
Balance	1,192	1,641	2,369	1,592		
Japan:						
U.S. exports	378	590	1,544	1,523	11.1	−1.6
U.S. imports	196	677	2,578	3,597	26.9	39.5
Balance	182	−87	−1,034	−2,074		
Canada:						
U.S. exports	1,829	3,111	5,608	6,673	13.6	19.0
U.S. imports	339	916	4,788	5,840	29.5	21.9
Balance	1,490	2,195	820	833		
Rest of world:						
U.S. exports	3,937	5,760	7,698	8,254	7.0	7.2
U.S. imports	471	235	910	1,088	8.3	19.6
Balance	3,466	4,841	6,788	7,166		

[1] Excludes special-category shipments.
[2] 26 West European countries.

Source: U.S. Congress, House, Committee on Science and Astronautics, "Science, Technology, and the Economy." 92d Cong., 2d sess., April 1972, p. 8.

On the other side of this debate were economists like Kindleberger, William Branson, Richard Nelson, and Michael Boretsky who argued that the deterioration in America's trading position was the result mainly of longer-term trends in America's competitive position. Due to a secular decline in America's economic performance and the "catching up" of her industrial competitors, the economic gap between the United States and other major industrial powers had largely closed. In effect, the United States had lost a substantial part of its traditional comparative advantages in manufacturing. The trade deficit represented a secular decline in America's economic position. The trade surplus of 1973, this perspective notes, was due in large measures to an unprecedented export of agricultural products, military equipment (especially to Israel), and the demand for U.S. capital goods of faster growing for ign economies. (Boretsky, 1975, p. 76). Moreover, the deficit in nontechnology-intensive products continued to grow despite the devaluation of the dollar and the deficit with respect to energy imports accelerated due to OPEC's five-fold increase in the cost of oil which was only made worse by the dollar devaluations. As a consequence, the trade deficit in 1974 was back up to $5.88 billion.

In Kindleberger's view the disturbing element was that this trade reversal was more than a normal change, i.e., exports being displaced by earnings from foreign investment. The critical factor was that the balance of payments on current account had turned adverse. The disappearance of an export surplus in merchandise trade indicated a deterioration of America's traditional dynamic comparative advantage—the tendency to replace dying exports with a new wave of innovative exports. Instead the United States appeared not only unable to hold its strong position with respect to older products, but it had not innovated new exports to take their place. Americans, Kindleberger surmised, like the British before them, had become more interested in consumption than production. (Kindleberger, 1974, p. 42.)

Behind this fading trade surplus and the decline of profit margins, certain economists have pointed to the fact that American productivity (output per manhour) has not grown as rapidly as that of her competitors. According to Commerce Department calculations (Table 3), the United States during the decade 1960–1970 had had the lowest productivity growth of any non-communist country. A remarkable decline in the rate of advance of American productivity is said to have taken place. During the first half of the twentieth century, American productivity had accelerated. Between 1879 and 1929, it had grown at an annual rate of 1.7 percent and at 2.4 percent between 1929 and 1957. Since the mid-1950s this rate appears to have dropped even when corrected for cyclical movement in output. (Nordhaus, 1972, p. 493.)

Annual growth rate of output per manhour

Period:	*Percent*
1948–55	3.11
1955–65	2.51
1965–71	1.88

TABLE 3.—COMPARATIVE GROWTH IN OUTPUT PER MAN-HOUR IN MANUFACTURING IN THE 1960's AND IN 1971

[In percent]

Country	Average annual growth in 1960-70	Growth in 1971 over 1970
United States	2.8	[1] 3.6
United Kingdom	3.3	6.2
France	5.9	2.8
West Germany	5.5	5.4
Italy	7.4	0
Japan	10.8	8.6
Canada	3.7	1.5

[1] In 1969 U.S. output per man-hour increased only 1.3 percent; thus the 1971 upswing does not bring up the 3-yr. average to the long-term trend presumed to be about 3.29 percent.

Source: U.S. Congress, House, Committee on Science and Astronautics, "Science, Technology, and the Economy," 92d Cong., 2d sess., April 1972, p. 9.

While some economists doubt the existence of a productivity decline and others believe that this drastic slowdown of productivity growth is cyclical and that it will revive, Nordhaus, Boretsky, and other economists believe it reflects long-term forces at work in the American economy, in particular, a large and accelerating shift toward industries with low productivity growth, especially services and government (Nordhaus, 1972). While their analyses differ, economists generally agree that the rate of productivity growth in the American economy has been substantially below that of America's major foreign competitors. If the more pessimistic analyses are correct, the implications are profound for the future competitiveness of the American economy.

In summary, the reason for America's declining economic position is undoubtedly some combination of the cyclical and secular positions. As we have seen, the trade balance did improve after the dollar was devalued in December 1971 and February 1973. What was significant, however, was that price competition had become increasingly important precisely because the United States had lost much of its former technological lead in many products and industrial processes. The United States had lost many of its technological advantages and had to compete against other industrial countries on the basis of price with declining profit margins. Moreover, it appeared not to be generating new exports through innovation in the civilian industrial sector. While relative technological decline and inadequate R and D in the civilian sectors have not been the sole cause of this low rate of productivity increase and deteriorating trade position, they have been an important contributing factor.

Since President Nixon initiated his New Economic Policy in August 1971 the American economy has been buffeted by a new series of major challenges: the unprecedented escalation of the price of oil by the OPEC cartel; double digit inflation combined with high unemployment and recession; and threats of shortages and cartel-formation in other areas of resources. As a consequence of these external and internal challenges, the United States must of necessity formulate a long-term strategy of economic and industrial rejuvenation.

Response to Decline: Three Available Strategies [2]

There are essentially three strategies which an economy can follow in response to its relative industrial decline. Certainly no country has pursued or probably could be expected to pursue, one of these three strategies to the exclusion of the others. But the relative emphasis on one strategy rather than another is of immense political and economic importance.

In the first place, such an economy can export capital in the form of loans or portfolio investments to industrialized economies. It can in effect become a *rentier* and increasingly live off the earnings from its investments overseas. Because the profit rates tended to be higher abroad than at home and financiers controlled her investment capital, this strategy of portfolio investment was the one chosen by Great Britain in the latter part of the nineteenth century.

A similar strategy has been followed by the United States increasingly since the end of the Second World War and more particularly after 1958. The strategy of foreign direct investment which has been emphasized by American multinational corporations is a far more complex phenomenon than the earlier British strategy. In part, it too is motivated by a differential rate of return on capital which favors foreign over domestic investment. However, if interest payments and capital gains were the sole motivation of American foreign investors, the pattern of American foreign investment would not be fundamentally different from that of Great Britain. And, in fact, substantial amounts of American foreign investment is portfolio investment.

The fundamental differences between the American strategy of direct investment and the British strategy of portfolio investment derive from the fact that the primary American investors are corporations rather than financiers or bankers. For this reason two other critical factors are involved in their decision to go multinational and to establish branch plants or subsidiaries overseas. These American multinational corporations seek to capture an additional rent on some oligopolistic advantage—a product or process innovation; a well-known trademark; or superior access to capital. The possibility of obtaining both a higher rate of profit than at home plus "monopoly rents" was not available to British investors, or at least to many of them. Moreover, the threatened loss of its monopolistic advantages and of market shares to foreign (or domestic) competitors is itself a further stimulus to foreign direct investment on the part of American corporations. For these several reasons, therefore, the "maturing" of the American economy has led to an immense outflow of capital in the form of direct investment.

In addition to this foreign investment strategy, there is, in theory at least, a second strategy available to the economy in response to its threatened relative industrial decline. This is the rejuvenation of the economy itself. In particular, this strategy implies the development of new technologies and industries and the redirecting of capital into neglected sectors of the economy. Through investment in re-

[2] These strategies and their implications are elaborated in my forthcoming book, *U.S. Power and the Multinational Corporations: The Political Economy of Direct Investment* (New York: Basic Books, September 1975).

search and development, for example, capital can be employed to innovate new products and industrial processes. In terms of foreign economic policy, this strategy implies a policy which emphasizes trade rather than foreign investment. For domestic and international political reasons, there is a sound basis for arguing that a greater emphasis on this strategy on the part of Great Britain in the nineteenth century would have served her national advantage. A similar argument can be made for the United States today.

There is yet a third strategy in response to relative decline; "reaction" is perhaps the most appropriate characterization. That is, an economy may withdraw into itself. As other economies advance, competition increases, and the terms of trade shift to its disadvantage, the declining economy retreats into protectionism or some sort of restricted preference system. It throws up barriers both to the export of capital and to the import of foreign goods. It favors preferential commercial arrangements. Too little is done to reinvigorate its domestic industrial base. This tendency is certainly one that has long been at work in the case of Great Britain; it is increasingly evident in the United States.

I have already hinted that a strategy of portfolio or direct investment may not be viable over the long run. Or, to put it another way it harbors the inherent danger that, as the host economies advance and the home economy declines, economic nationalism in the former and politicization in the latter undermine the political base which has supported a policy of foreign investment. Groups in both host and home economies turn against foreign investment. The economy is both pushed and pulled back into itself. Unfortunately, this withdrawal does not of itself give rise to a technological and industrial rejuvenation of its industrial economy. Instead the grave danger is that the economy will tend to stagnate. The reasons for this concern are very real.

Industrial economies tend to be highly conservative and resist change; the generation of new products and production processes is an expensive one for industrial firms with heavy investment in existing plants; labor can be equally resistant. The propensity of corporations is to invest in particular industrial sectors or product lines even though these areas may be declining. That is to say, the sectors are declining as theaters of innovation; they are no longer the leading sectors of industrial society. In response to rising foreign competition and relative decline, the tendency of corporations is to seek protection of their home market or new markets for old products abroad. Behind this structural rigidity is the fact that for any firm, its experience, existing real assets, and know-how dictate a relatively limited range of investment opportunities. Its instinctive reaction therefore is to protect what it has. There may be no powerful interests in the economy favoring a major shift of energy and resources into new industries and economic activities. In short, an economy's capacity to transform itself is increasingly limited as it advances in age.

Regrettably, the rejuvenation of an economy and the shift of resources to new leading sectors would appear to be the consequence of catastrophe such as defeat in war or an economic crisis. It took near-defeat in the First World War for Great Britain to begin to restructure her economy, though even then she did not go far enough. It is not surprising today that the two most dynamic industrial powers—Japan and Germany (East and West)—were the defeated nations in the last World War. Nor is it surprising that outside the military realm, the two victors—the United States and the Soviet Union—are falling behind industrially.

There is good reason to believe, as Peter Drucker (1969) and others have argued, that the United States and its economic partners have exhausted many of the innovative possibilities of the industries upon which American economic power, foreign investment, and the immense growth of the last several decades have rested such as the internal combustion engine, manmade fibers, electronics, and steel. The growth curves of these industries, much like those of cotton, coal, and iron in the last century, appear to have flattened out. They appear to have ceased to be major theaters of innovation and future industrial expansion, at least in the developed countries. Thus, with the exhaustion of technological opportunities and the closing of the technology gap in commercial (though not military) technology among the industrial and the industrializing countries, economic conflict among industrial economies has greatly increased.

In the contemporary world, the shortening of the international product cycle due to the more rapid diffusion technology, the liberalization of trade, and the emergence of many industrial economies, have intensified competition. Profit margins have declined; investment and growth have slackened. The industrial world could well enter a period of mercantilistic conflict similar to that which characterized the period prior to World War One and also the inter-war period. As a consequence, though we may neither have reached the "limits to growth," as some doomsday prophets hold, nor be entering the severe depression phase of a Kontratieff wave, as others argue, the world is certainly entering an era of major adjustment to new economic realities.

In the short run, economic conflict has been intensified by the energy crisis, shortages of resources, and world-wide inflation. Yet, viewed from a longer perspective, the critical issues of resources, environment and inflation could have a beneficial effect. They may constitute the "catastrophe" which could stimulate a rejuvenation of the American economy. In the search for solutions to these pressing problems, the United States is being forced to innovate a new order of industrial technology and economic life. If this search leads to technological breakthroughs and the fashioning of a new international division of labor we may yet escape the mercantilistic conflict and economic decline which threaten us.

The argument of this report is that the United States must adopt the strategy of rejuvenation of its domestic industrial and economic base. In place of our present emphasis on the overseas expansion of American corporations and the opposed tendency to retreat into protectionism, the United States should initiate policies directed toward the rejuvenation of its civilian industrial economy. One necessary ingredient in such a rejuvenation strategy, but by no means the only one, is an improved capacity in civilian-related R and D. Toward the achievement of this goal, the emphasis of this report is upon national policy for scientific research and technological innovation.

III. THE STATUS OF RESEARCH AND DEVELOPMENT

A fundamental problem of American science and technology is that our priorities have been too much determined by the Cold War with the Soviet Union and by considerations of national prestige. In the judgment of Harvey Brooks, one of America's more astute students of the subject, the problem lies in the fact that the United States has over-specialized for an economy of its size (Brooks, 1972). As Tables 4 and 5 reveal, an inordinate proportion of our total national scientific and technical resources has been devoted to a relatively few areas of "big science and technology: space, defense, and atomic energy." In contrast to the Japanese and West Germans, for example, a much smaller fraction of our total R and D effort has been devoted to civilian industrial technology. In short, despite the billions that the United States has invested in R and D, we have actually *under-invested* in civilian industrial research and development.

FINANCIAL SUPPORT FOR RESEARCH AND DEVELOPMENT

After rising at an annual rate of 12.6% from 1953 to 1964, total R and D spending advanced at only a 5% pace from 1964 to 1971. (*The Morgan Guaranty Survey*, February 1972, p. 3.) In real terms because of inflation, the rate was closer to 3 percent. One hopeful sign in the present situation is that the proposed civilian R and D budget for 1976 is a 12 percent increase over 1975. One-fourth of this increase is for energy, and, as we shall see, there is a basis for concern with respect to the emphasis within this budget.

TABLE 4.—CHANGE OF PERCENTAGE SHARES OF MILITARY, SPACE AND NUCLEAR R. & D. EXPENDITURES AS A PROPORTION OF TOTAL PUBLIC R. & D. EXPENDITURE DURING THE 1960'S

Country	1960–61				1969–70			
	Defense	Space	Nuclear	Total	Defense	Space	Nuclear	Total
United States	68.7	9.1	10.7	88.5	48.7	23.2	6.5	78.4
Canada	23.2		21.2	44.4	11.2	1.4	19.5	32.1
Belgium	6.0		24.3	30.3	2.0	6.0	14.8	22.8
United Kingdom	64.5	.5	14.7	79.7	40.4	3.7	11.5	55.6
Norway	8.6	.4	16.5	25.5	7.1	1.2	8.3	16.6
Japan	5.6		7.6	13.2	2.2	.7	7.4	10.3
Sweden	49.0	.1	23.9	73.0	28.3	1.5	9.4	39.2
Netherlands	5.0	.2	11.7	16.9	4.5	2.9	10.5	17.9
France	41.5		27.5	69.0	30.7	6.7	17.8	55.2

Source: OECD Statistics (1971).

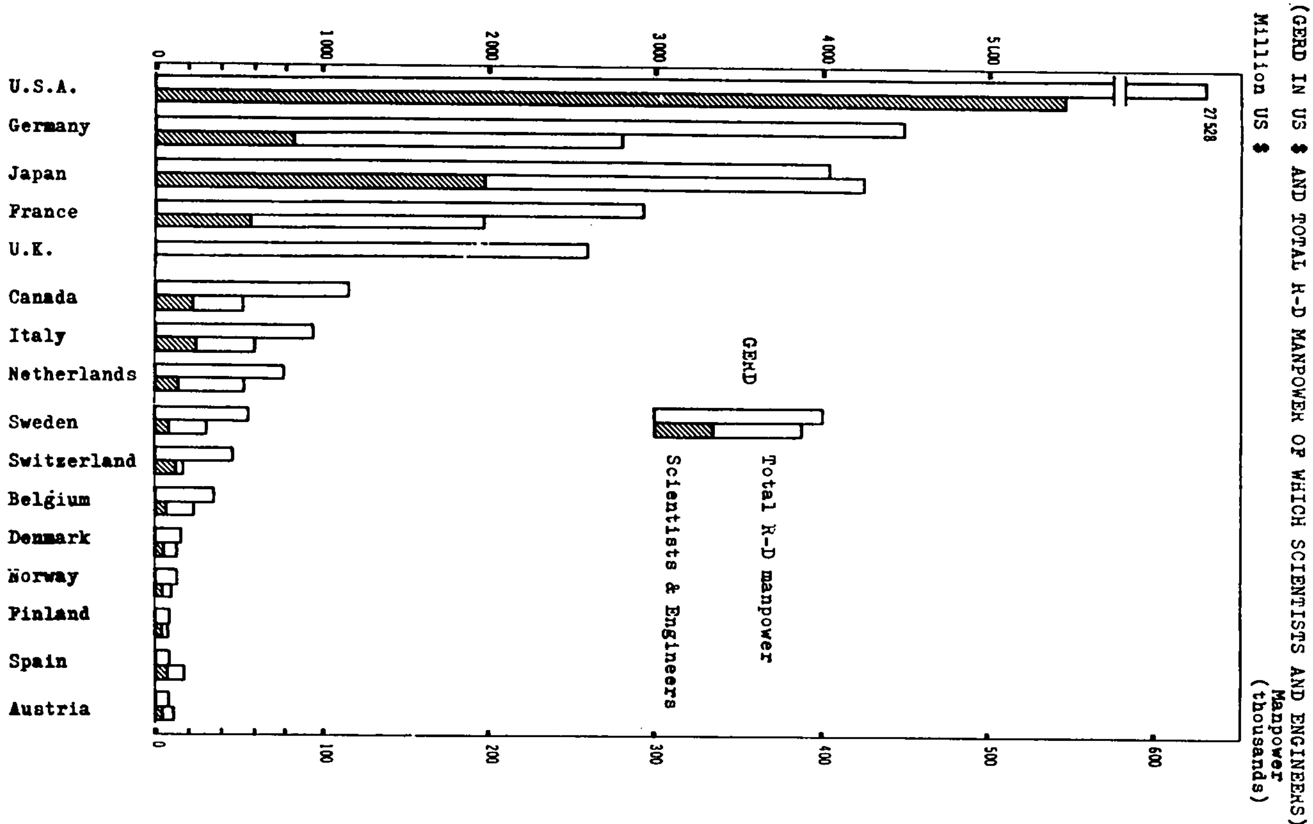
TABLE 5.—PERCENTAGE SHARES OF PUBLIC R. & D. EXPENDITURES

Country	1960–61				1968–69			
	Military, space, nuclear	Economic, agriculture, manufacturing services	Welfare, health, environment	Other, including university	Military, space, nuclear	Economic, agriculture, manufacturing services	Welfare, health, environment	Other, including university
United States	88.5	3.2	7.3	1.1	79.3	6.0	12.7	1.9
Canada	44.4	32.2	3.3	20.1	28.7	48.9	11.3	11.1
Belgium	30.3	26.4	4.0	39.3	24.4	26.9	3.7	45.0
United Kingdom	79.7	11.2	1.7	7.5	59.4	22.1	3.7	14.8
Norway	25.5	31.7	7.8	35.0	16.8	39.7	8.3	35.2
Japan	13.2	32.5	2.6	50.8	8.7	25.0	4.0	62.2
Sweden	73.0	7.3	4.7	15.0	52.2	13.1	8.2	26.3
Netherlands	16.9	23.7	10.0	50.2	19.4	18.0	9.3	53.2
France	69.0	7.9	.9	22.2	55.2	16.5	2.7	25.6

Source: OECD statistics, 1971.

As shown by Graphs A and B the American R and D effort in terms of gross expenditures on R and D (GERD) and scientific/technical manpower still dwarfs that of all the other OECD countries. However, as shown by Graphs C and D, the growth rate and absolute amounts of American funds and manpower devoted to R and D have actually declined in recent years. At the same time, Japan and West Germany have increased their R and D expenditures. More importantly, from the perspective of this report, these two nations devote a far higher percentage of R/D funds to the advancement of the civilian economy (Graphs E and F and Tables 4 and 5). While a much higher proportion of industrial R and D in the United States is financed by government, a very large fraction of these funds is devoted to defense, nuclear, and space R and D (Graphs G and H). In short, although the United States invests heavily in R and D, relative to her principal foreign competitors, the United States trails Japan, West Germany, and certain other countries with respect to civilian industrial R and D.

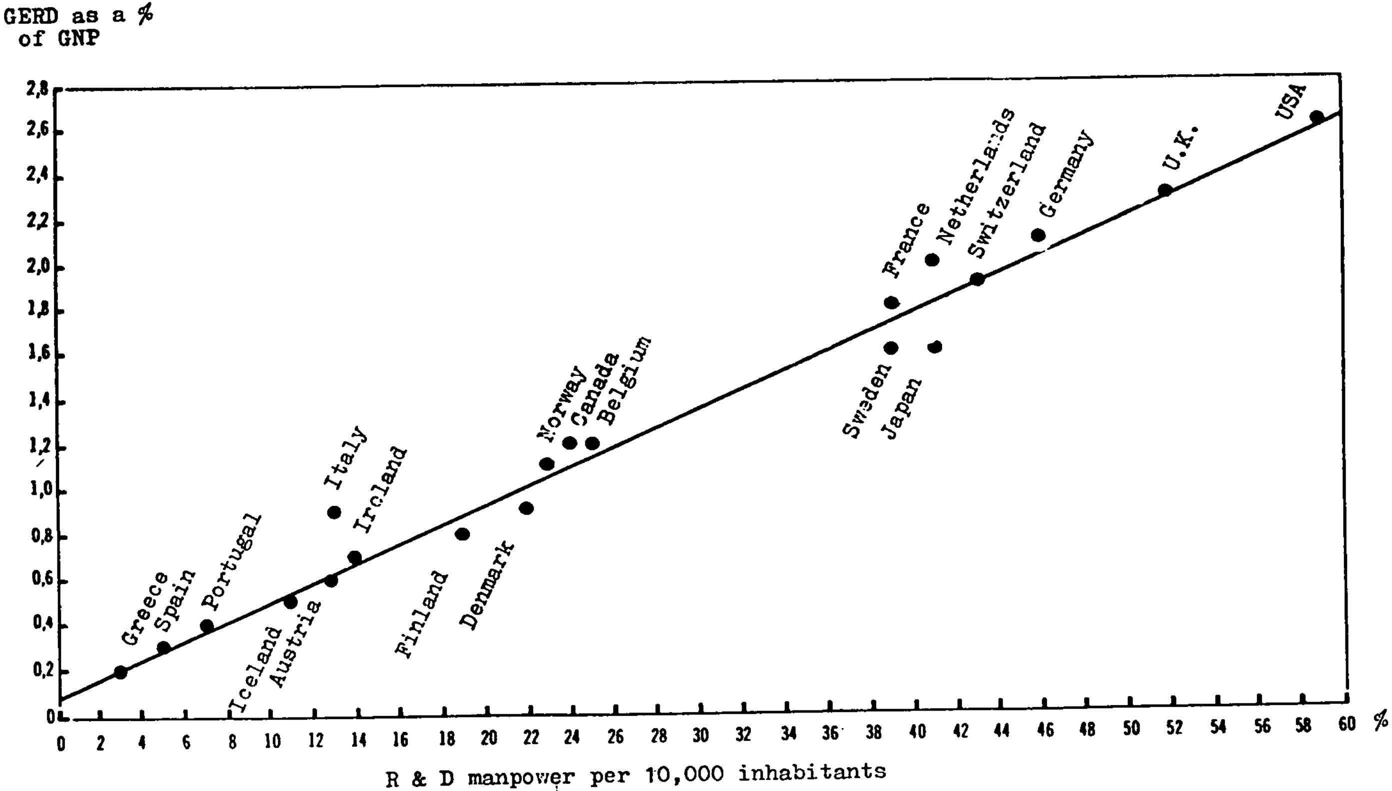
GRAPH A.—Absolute Amount of Resources Devoted to R. & D. in OECD Member Countries in 1970–71.



The scale chosen does not permit the inclusion of Ireland, Portugal, Greece and Iceland.

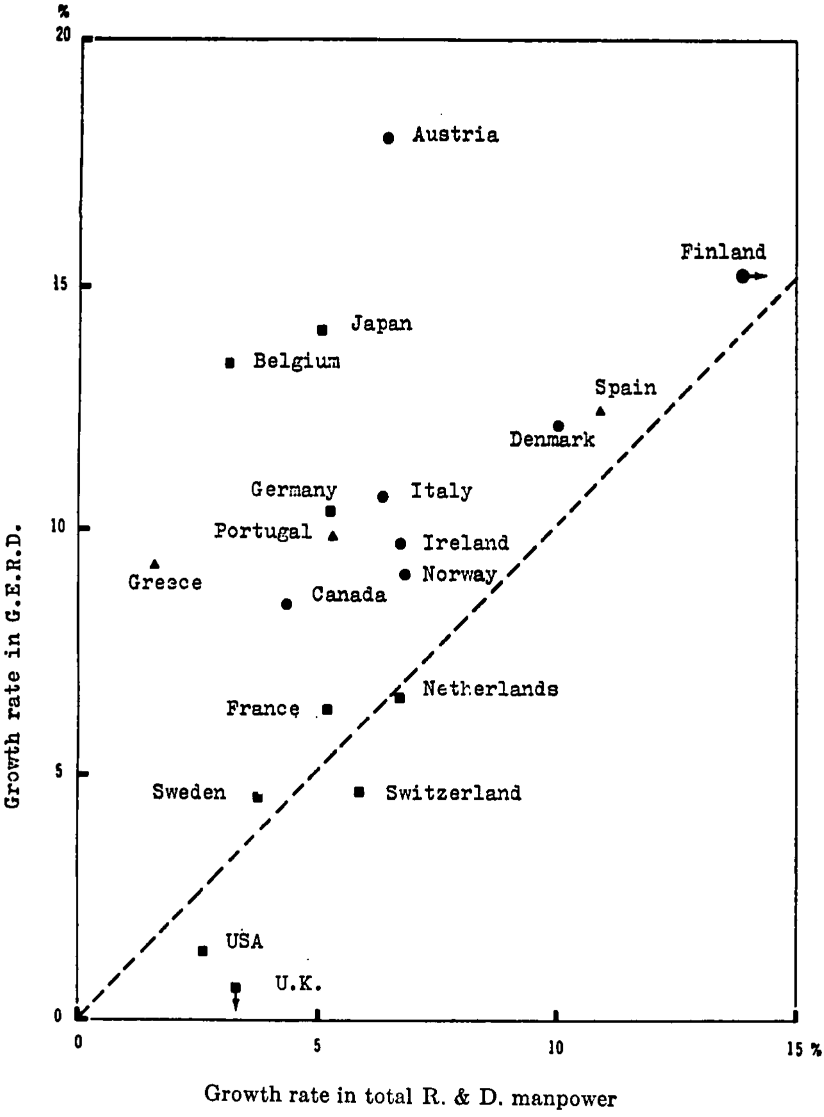
Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963–1971" (Mimeo), May 17, 1974, p. XII.

Graph B.—National R. & D. Efforts Compared With Total National Resources, 1971.



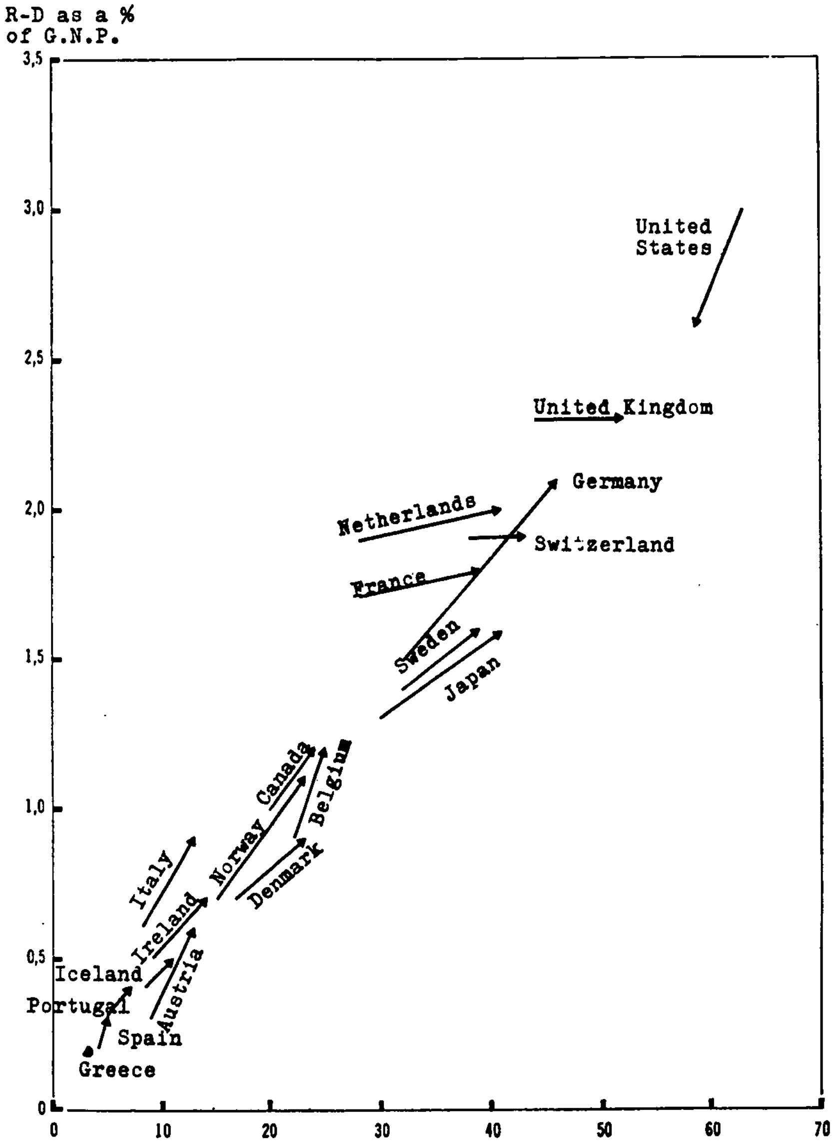
Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963–1971" (Mimeo), May 17, 1974, p. 4.

GRAPH C.—Average Annual Growth Rates in G.E.R.D. and Total R. & D. Manpower Between 1963-64 and 1970-71.



Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963-1971" (Mimeo), May 17, 1974, p. 8.

GRAPH D.—Changes in the Relative Amount of Resources Devoted to R. & D. Since 1963–64.

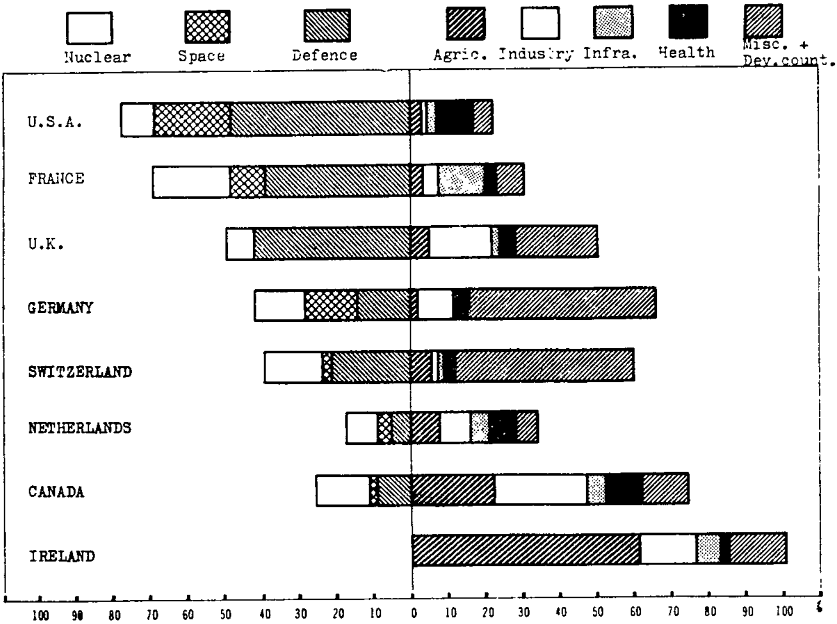


R. & D. manpower per 10,000 inhabitants

Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963-1971" (Mimeo), May 17, 1974, p. 10.

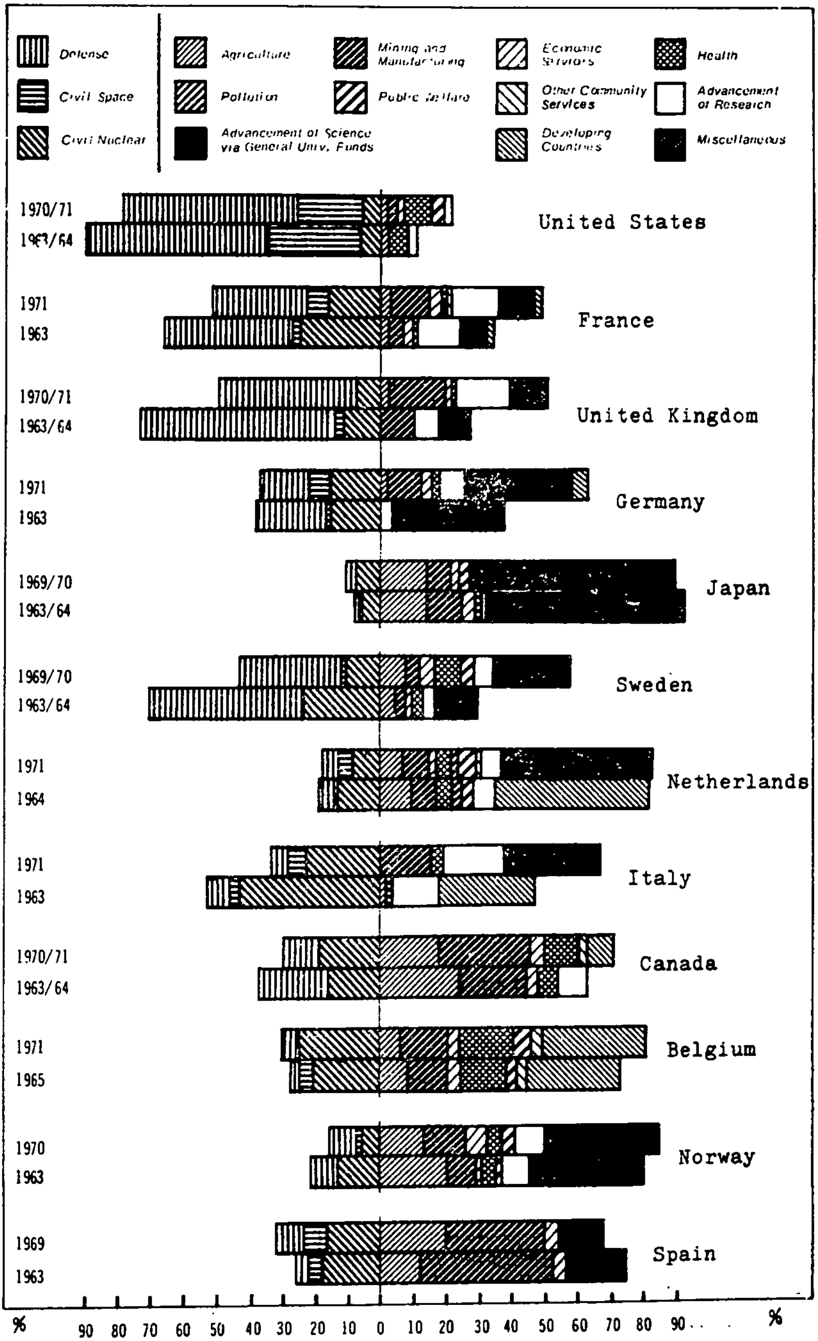
GRAPH E.—Total Government R. & D. Expenditure by Objective, 1971 (Percentages).

(Based on ISY Data)



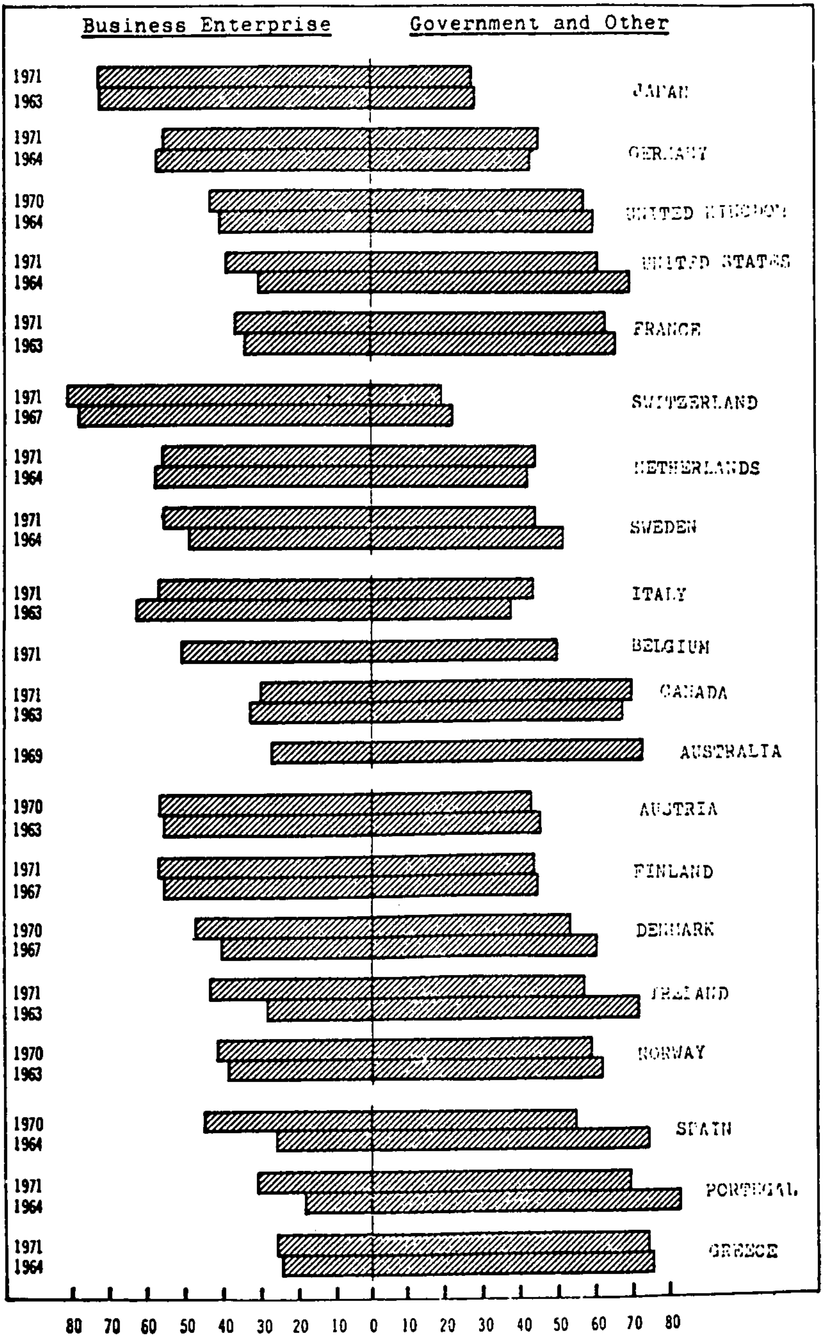
Source: OECD, Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963–1971 (Mimeo) May 17, 1974, p. 28.

GRAPH F.—Total Government R. & D. Expenditure by Objective 1963 and 1971.



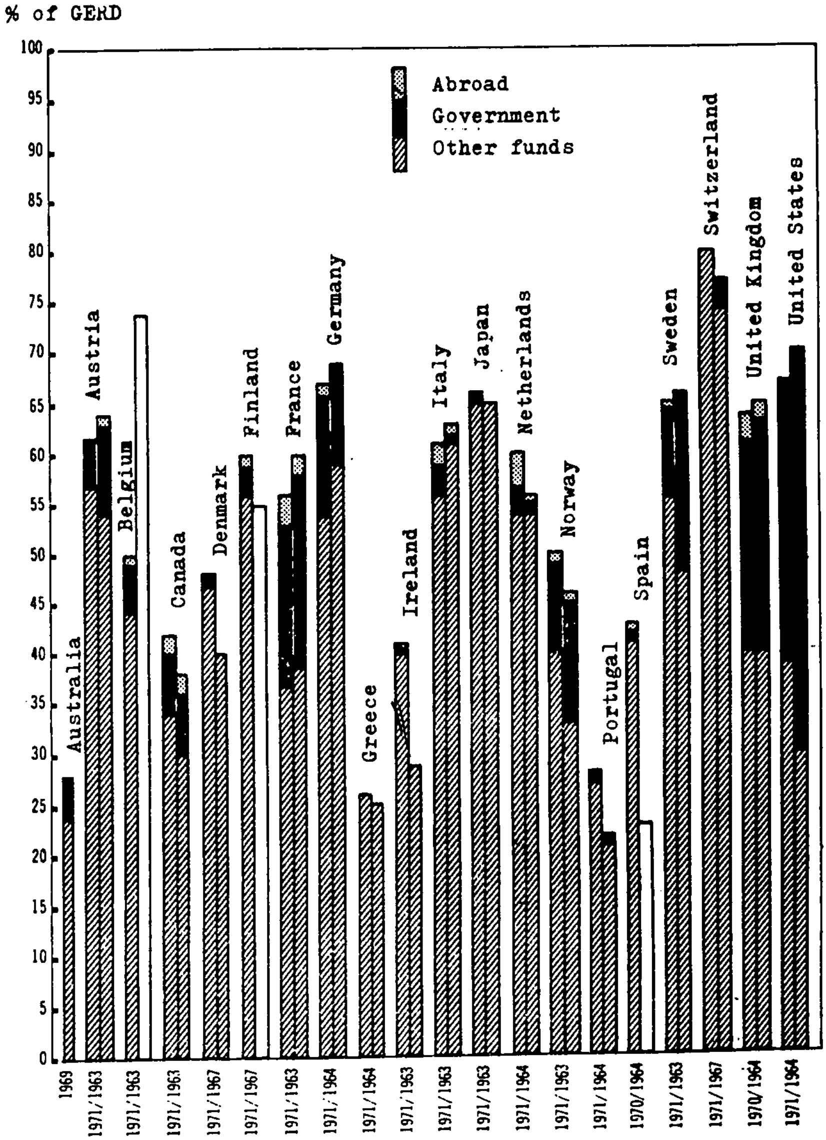
Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963-1971" (Mimeo), May 17, 1974, p. 32.

GRAPH G.—GERD by Source of Funds (Percent) 1970–71 and 1963–64.



Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963–1971" (Mimeo), May 17, 1974, p. 18.

GRAPH H.—R. & D. Performed in the Business Enterprise Sector by Source of Funds, as a Percent of GERD in 1970–71 and 1963–64.



Source: OECD, "Patterns of Resources Devoted to Research and Experimental Development in the OECD Area, 1963-1971" (Mimeo), May 17, 1974, p. 40.

Although American industry, according to the latest McGraw-Hill survey, will increase R and D spending this year by 10 percent over 1974, in real terms industry's total spending will increase very little. Moreover, three sectors (aerospace, electrical machinery, and communications) account for nearly 50 percent of industry's projected expenditures. Energy development will also be emphasized. Unfortunately, however, the accelerating cost of R and D due to inflation is causing American industry to decrease its funding of new product development; the focus of industrial R and D will be on the improvement of existing products. In the words of McGraw-Hill's chief economist, "an increasing volume of new products contributes to faster economic growth while declining volume suggests slower future growth. Improving existing products ranks ahead of new product development currently." (*The Wall Street Journal*, May 8, 1975.) Thus, in response to contemporary economic difficulties, the instinctive response of industry is to decrease its expenditures on the innovation of new products which would contribute most to economic growth and international competitiveness in the long run.

A composite picture of American R and D expenditures is provided by Figure 2. Total R and D expenditures, particularly for development, have declined in terms of constant 1958 dollars and as a percentage of GNP. Industry's funding of R and D has leveled off in terms of constant 1958 dollars, although R and D expenditures by industry have remained constant as a percentage of GNP. While funding for applied research has leveled off, basic research funding has decreased slightly in terms of constant 1958 dollars. Finally, civilian-related programs including energy, health, education, agriculture, environment, urban problems, transportation, and other programs have expanded considerably since 1967. However, approximately one fourth of the civilian R and D budget for 1976 is planned for energy-related activities especially atomic energy and more particularly, the breeder reactor.[3]

What these statistics and the foregoing analysis reveal is an overall deemphasis on R and D in the United States relative to past expenditures and relative to America's economic competitors. Although projected private and public expenditures indicate an increase over the recent past in expenditures in real terms, the primary emphasis will be on energy development, especially atomic energy. While a greater recognition is being given to the problem of civilian technology, the judgment of this report is that a much higher level of performance is required with respect to civilian-industrial R and D if the United States is to resolve its domestic problems and meet intensified international competition.

It would make the task of this report much easier if one could determine in quantitative terms what this "higher level of performance" should be, and how R and D funds should be allocated in order to

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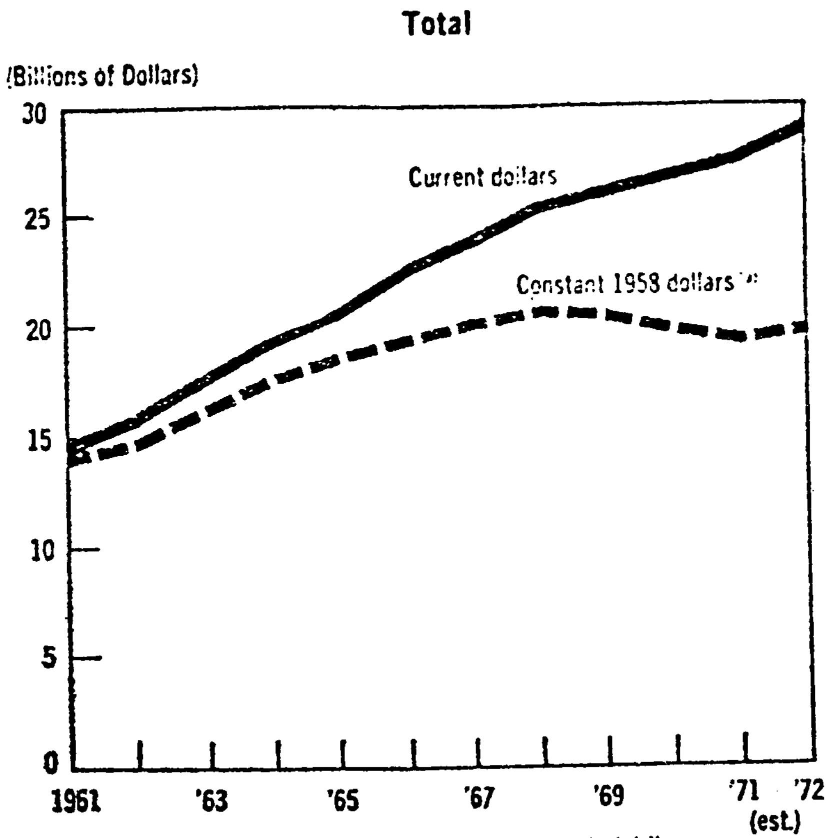
[3] Office of Management and Budget, Special Analyses Budget of the United States Government, Fiscal Year 1976, Special Analysis P, *Federal Research and Development Programs*, U.S. Government Printing Office, 1975, p. 252.

obtain an optimum rate of return. Unfortunately, as the authors of what is undoubtedly the best study by American students of the economics of R and D have concluded: "the present state of knowledge is not strong enough to permit quantitative determination of the rate of return in different activities, and thus does not permit policy recommendations to be derived from optimization principles" (Nelson et al, 1967). For this reason judgments concerning these matters will differ. For this reason, too, rather than argue for this or that level of expenditure on R and D or for support of this or that particular R and D program, the emphasis of this report will be on the appropriate approach which the government should take toward civilian technology. In other words, what should be the national strategy toward R and D in order to foster the rejuvenation of the American economy?

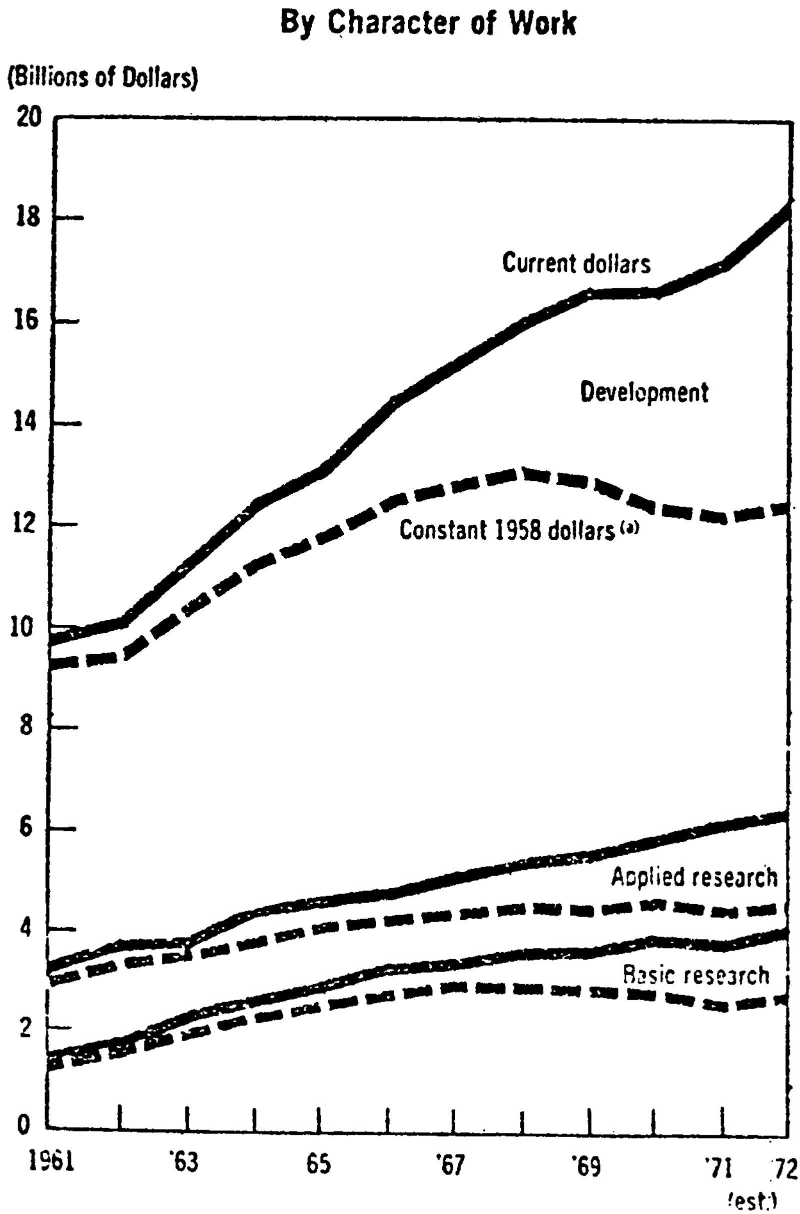
FIGURE 2.—National R. & D. Expenditures, 1961–72.



(a) GNP price deflator was used to convert current to constant dollars.

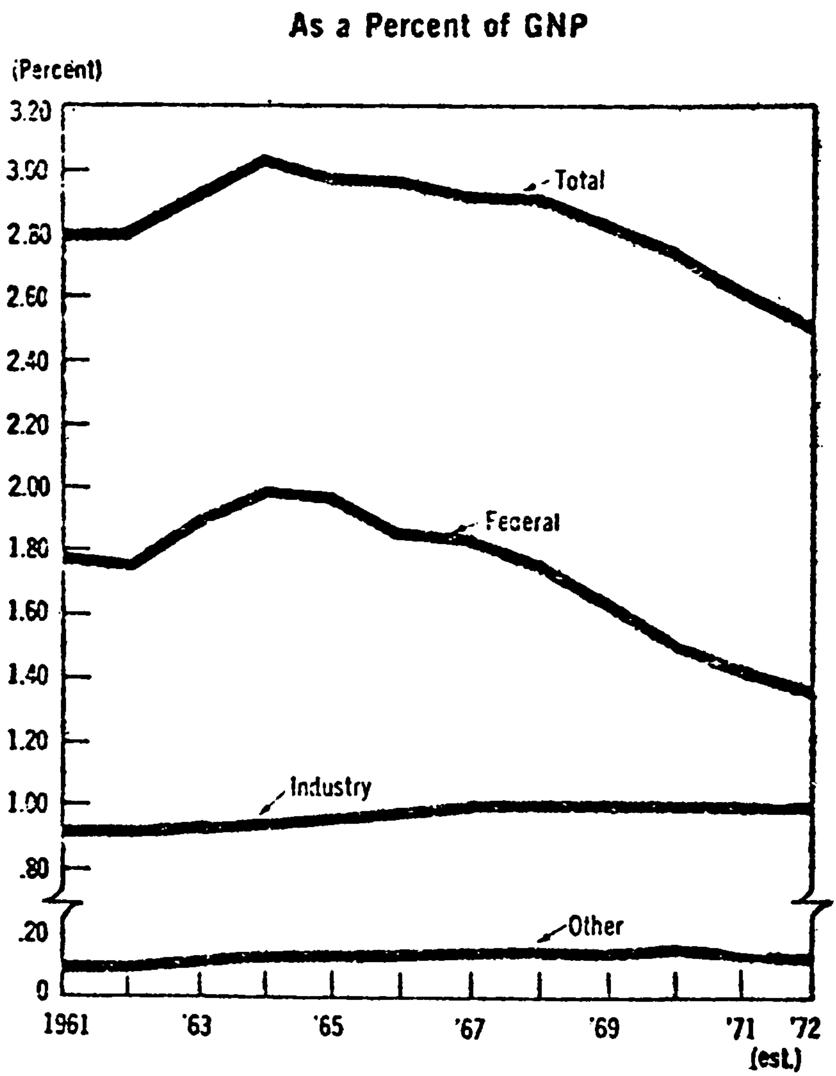
Source: National Science Foundation, *Science Indicators*, 1972, p. 22.

FIGURE 2.—Continued



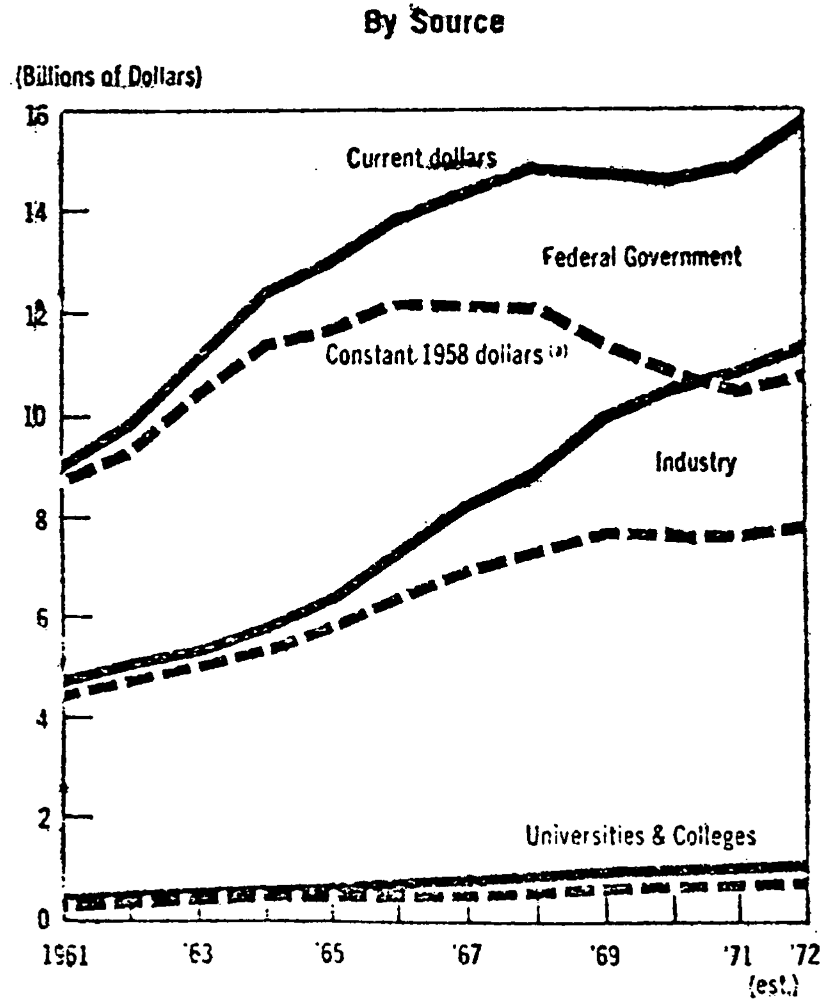
(a) GNP price deflator was used to convert current to constant dollars.
Source: National Science Foundation, *Science Indicators*, 1972, p. 22.

FIGURE 2.—Continued



(a) Total GNP price deflator was used to convert current to constant dollars.
NOTE: Other nonprofit institutions R. & D. expenditures increased from $110 million in 1961 to $235 million in 1972.

FIGURE 2.—Continued



(a) Total GNP price deflator was used to convert current to constant dollars.
NOTE: Other nonprofit institutions R. & D. expenditures increased from $110 million in 1961 to $235 million in 1972.

PRESENT GOVERNMENT POLICY FOR CIVILIAN R. AND D.

In the early 1970s, several developments focused official attention on the nature and status of America's overall effort in science and technology. In the first place, the abating of the Cold War and the reduction of tensions with the Soviet Union undercut the support for massive military and space programs. From a peak of $5.5 billion in 1965, NASA was cut back in 1971 to $3.4 billion, a drop from 35 percent to 20 percent of public R and D expenditures. (Freeman, p. 294.) Nuclear research was also cut back during this period. As public expenditures for R and D approached the annual expenditures of $20 billion more and more questions began to be raised.

Secondly, public attitudes toward science and technology changed in the late 1960s and early 1970s. The Senate vote against the SST was a harbinger of growing public skepticism regarding the costs and benefits of "big technology." The Mansfield Amendment debarring the military and space agencies from supporting university scientific research not directly relevant to the attainment of their objectives hit at "big science." The establishment of the Office of Technology Assessment to monitor the social and economic consequences of technological innovations reflected the public concern that the costs of technological development were beginning to exceed the benefits.

And thirdly, a sense of new national priorities began to emerge. The re-entry of Japan and Western Europe into world markets had increased international economic competition and forced attention on the competitiveness of American industry. Technology became recognized as an important economic resource which could lift industrial productivity and create exports. Events of the 1960's and early 1970's also focussed attention on domestic social and welfare needs: urban decay, the plight of the Penn Central Railway, environmental pollution. And finally, the Arab petroleum boycott in conjunction with the Arab-Israeli War of 1973, the threat of general resource scarcities, and the advent of double digit inflation focussed attention on the prices and security of energy supplies, food, and other resources. In short, the force of events was calling attention to domestic economic and social needs of American society and demanding that American science and technology contribute to making America more competitive economically and more liveable socially.

The increasing concern over America's deteriorating position in technology-intensive exports (and the rising unemployment in the aerospace industry due to the leveling off of the defense-space program) led in the early 1970's to ambitious plans for a major government effort to fund civilian technology. Spearheaded by a White House Agency, this New Technological Opportunities Program proposed to funnel hundreds of millions of dollars into the private sector, especially the aerospace industry, to develop big technologies. In effect, this program would have carried over into the area of civilian technology, the government-industry relationship which exists in the defense-space sector namely crash programs, government assumption of the entrepreneurial function, and government funding of commercial development.

A subsequent section of this report will consider the dangers of incredible wastage inherent in this approach to technological innovation which has unfortunately been carried over in large measure to Project Independence. For the moment, what needs to be said is that among the many projects contemplated by the Technological Opportunities Program, only two major projects received serious consideration. The high cost of the program ($2 billion estimate) and lack of strong political support prevented the others from seeing the light of day. Of these two, one—the project for a supersonic transport (SST)—went down to defeat in the Congressional fight over its environmental effects and highly questionable commercial merits. The other—the breeder reaction for nuclear power—was funded and has now become the primary development effort under Project Independence.

As George Eads and Richard Nelson pointed out at the time, this Technological Opportunities Program represented a major departure in government policy: government subsidization of large-scale research and development on non-military products (Eads and Nelson, 1971; Nelson 1971). In effect, the government would take over the entrepreneurial function and assume the risk in the development of large, commercial technologies. The program meant government "subsidy or financial support of the development of products for production and sale by private companies through the market to the civilian sector (prominently including the export sector.)" (Nelson 1971, pp. 392–93.) Thus, the Nixon Administration was proposing an extremely costly and unprecedented government intervention in the private sector of the economy.

In addition to the ill-fated New Technological Opportunities Program the concern in the early 1970s over civilian R and D, export competitiveness, and the general state of the American economy gave rise to several other programs in the Department of Commerce and the National Science Foundation: the Experimental Technology Incentives Program of the National Bureau of Standards, the Experimental R and D Incentives Program of the NSF, the National R and D Assessment Program of NSF, and the Research Applied to National Needs Program (RANN) also of NSF. In addition, the Commerce Department was made the executive branch's "focal point" for policy development on industrial R and D.

The Experimental Technology Incentives Program (NBS) and the Experimental R and D Program (NSF) were established to develop experimental contract programs to study means by which the federal government could best stimulate research and development in the civilian sector. RANN was assigned the task of funding scientists and engineers to work on specific social and economic problems. The National R and D Assessment Program was set up "to supply objective analyses and define options for enhancing the contribution of science to the nation" and at the Department of Commerce, a number of reorganizations occurred and responsibilities were changed to improve its ability to carry out its newly assigned leadership task with respect to civilian industrial technology.

Unfortunately, for one reason or another, none of these programs have yet fulfilled the high expectations of their creators, though only one or two can be described as "failures." The reasons for this lack of success are a matter of dispute, they range from inadequate funding to poor management. Some critics suggest that the NSF with its emphasis on basic scientific research is a poor location for a program trying to stimulate applied or industrial research. Other critics argue that the wrong approach to technological innovation was taken. The emphasis was incorrectly placed on "technology-push" rather than a "demand-pull" (See below). As for the Department of Commerce's leadership role, skeptics point out that it is ill-suited for undertaking such a responsibility. The Experimental Technology Incentives Program will be discussed further below.

At the same time that these initiatives (however ill advised some of them proved to be) were undertaken, the Nixon Administration made a decision which is the judgment of many observors was a major error. For reasons which lie outside the compass of this report, the office of the Science Advisor to the President was eliminated and its responsibilities were transferred to the Director of the National Science Foundation. Thus, the Administration appeared to downgrade science and technology and created a leadership gap with respect to science and technology at the highest level of the executive branch. While the Federal Council on Science and Technology composed of the science officials of each government agency was retained, this Presidential action greatly weakened the scientific advisory and leadership mechanism which had been created by President Eisenhower.

In addition to the growing R and D activities of several departments (Transportation, Housing and Urban Development, etc.), and until the creation of the Energy Research and Development Agency (ERDA) in 1974, the situation described above generally characterized the government's role with respect to R and D in the civilian industrial sector. In a subsequent section, this report will discuss ERDA. For the moment, let us consider the relationship of the government to the third leg of the national R and D triangle—universities and institutions of higher learning, including schools of engineering.

Government Support and University Research

Ultimately the innovative capacity of American society and industry is dependent upon the health of American higher education and its output of scientists and engineers. As the transfer of knowledge is "person embodied," the flow of scientific and engineering graduates from universities and engineering schools into the industrial and public sectors is an important part of the innovative process. It results in the transfer of new scientific and technical knowledge from university and engineering research programs to industry or government where it can be applied. For this reason, the financial crisis of higher education and the decline of government funds for basic scientific and technical research programs threaten the long term health of American industry and society.

Over the past five years, many studies and reports have analyzed this situation and have recommended one solution or another. This report can add little which has not already been said. But there is one aspect of the present crisis of universities and university research which has not been sufficiently emphasized. This is the effect on universities of the shift in national priorities from the arms race and the Cold War to economic growth, economic competition, and domestic social priorities.

These security and prestige-related programs were especially beneficial to university research, or at least to certain sectors of higher education. This assessment, I appreciate, is highly controversial. It runs counter to the view that military support perverted university science, a view reflected in the Mansfield amendment barring military funding of university research unless a military need can be demonstrated. On the contrary, the military services on the whole have been excellent patrons of university research; the present crisis of university basic research and engineering stems in large measure from the withdrawal of this support, though the effects of this support are not free from criticism. As in the case of government financing in general, there were problems; the emphasis on particular areas and the neglect of others caused serious distortions and imbalances in the overall national basic and applied research effort. Government over-financed "big technology" and "big science" such as aeronautics, particle accelerators, and electronics to the detriment of technologies and sciences of equal or greater relevance to social welfare and civilian industry.

Contrary to the argument of the critics that basic research in the universities and engineering research became a captive of the military, what one had in effect was an alliance between particular government agencies and particular academic disciplines and institutions of higher learning. During the Second World War, a new generation of American scientists and technologists matured which was dedicated to transforming American university research. They desired American universities and engineering schools to become major centers of research in the advanced areas of science and technology which were then coming into prominence: theoretical and costly experimental physics, polymer chemistry, electronics, aeronautics, and, later, solid state physics. For its part, the military and certain other government agencies desired the same type of advanced sciences and technologies. In the name of national security, plentiful funds were available and the government financed a relatively broad spectrum of research in these newer areas, especially in the more prestigious institutions: MIT, Harvard, Princeton, the University of California, the University of Michigan, the California Institute of Technology, and so forth. Scientists and engineers were relatively free to pursue their own research interests because the interests of the military services, the Atomic Energy Commission, and the National Aeronautics and Space Administration were sufficiently broad to encompass whatever came out of the university laboratories. No doubt too these agencies were seeking the good opinion of university researchers. No doubt too a lot of "waste" was involved.

In addition to the corrosive effects of inflation and overexpansion of staff and facilities, the crisis of university basic and applied research stems in large measure because this alliance has weakened. Government funds have decreased and national priorities are shifting to newer areas of domestic concern. Moreover, a new generation of university researchers is coming onto the scene which is interested in newer areas of research: energy and resources, food production, environmental pollution, mass transportation, urban technologies, and other newer fields of basic research and engineering. At the same time, with the end of rapid university expansion, universities are decreasingly able to create academic positions in these newer areas of concern. The universities at this time are too much geared to the priorities of big technology and certain theoretical fields of decreasing social-economic relevance. While the conversion of university research to those newer national priorities is possible and is taking place, it is difficult. As one of my more cynical colleagues put it, "It is fascinating to witness aerospace engineers and high powered theoretical physicists becoming interested in a fast moving field like sewage disposal." But it is happening as high powered aeronautical engineers, physicists, and economists turn their talents to such important areas as new forms of energy generation or fertilizer production.[4]

The problems posed for university research by the shift in national priorities, the rigidities of the tenure system, the over expansion of the universities, and the effect of inflation raise profound issues which go beyond the scope of this report. Yet, what this situation suggests is the need for a new alliance between government, university and private industry in newer areas of concern to replace the declining efficiency of the anachronistic alliance forged at the end of the Second World War. On the university side the situation is ripe for cooperative efforts which would invigorate scientific and technical research relevant to our emergent set of national priorities.

Unfortunately, the government side of this potential alliance has yet to develop its full potential. On the contrary, as we have already seen, the intricate and complex mechanisms created over the past several decades for policy making with respect to science and technology and for involving scientists and technologists in national policy have in large part been destroyed or at least considerably weakened. Only government can provide the leadership which is required, and the present structure centering upon the Director of the National Science Foundation is inadequate for the task at hand. But there is another problem which requires emphasis.

Unlike the Department of Defense, the AEC, and NASA, the government agencies with primary responsibility for the emerging set of national priorities too frequently lack an appreciation of the importance of basic research and exploratory development. Moreover, in carrying out their missions, they too seldom appreciate how their policies affect technology and how the achievement of their responsibilities could be improved through policy research and experimentation. Furthermore, as revealed by Table 6, certain of the agencies with research programs tend to do R and D in their own laboratories; they do not sufficiently draw upon or support university or industrial research and development. This is true even of such an important research-oriented department as that of Agriculture which has funded relatively little basic research or research outside the Department itself and its Experimental Stations despite the fact university science and engineering departments could contribute much to the technology of food production.[5] In short, as Defense and other agencies withdraw from the support of science and technology, they are not being sufficiently replaced by the agencies concerned with our emergent set of national priorities.

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[4] For example, the Aerospace Research Laboratory at the University of Washington is working on the critically important problem of nitrogen fixation. See A. Hertzberg, "Nitrogen Fixation for Fertilizers by Gasdynamics Techniques" (mimeo), November 29, 1974.

[5] This is the basic criticism and recommendation of the *Report of the Committee Advisory to the U.S. Department of Agriculture* (1973).

TABLE 6.—TOTAL AND INTRAMURAL R. & D. OBLIGATIONS, BY FEDERAL AGENCY, 1969 [1]

Agency or Department	R. & D. obligations (in millions) Total	Intramural	Percent intramural	Year unit established
Treasury	$0.6	$0.6	100	1789
Veterans' Administration	50.2	49.2	98	1930
Tennessee Valley Authority	8.3	8.1	98	1933
Smithsonian Institution	14.8	13.6	92	1846
Commerce	72.1	57.8	80	1913
Labor	12.2	8.6	80	1913
Agriculture	260.1	190.3	73	1862
Arms Control and Disarmament Agency	6.0	4.2	70	1961
Interior	207.6	123.4	59	1849
Army	1,643.8	567.6	35	1789
Navy	2,124.2	708.9	33	1798
Defense Agencies [2]	429.6	132.1	31	1947
State	20.3	6.2	31	1789
Post Office	19.4	5.2	27	1872
Transportation	228.0	53.7	24	1966
National Aeronautics and Space Administration	3,963.3	820.9	21	1958
Health, Education, and Welfare	1,297.4	243.4	19	1953
Air Force	3,498.5	458.7	13	1947
Housing and Urban Development	18.2	2.1	12	1965
Office of Economic Opportunity	70.6	5.9	8	1964
Justice	4.8	.4	8	1870
National Science Foundation	273.8	15.0	5	1950
Atomic Energy Commission	1,405.9	17.0	1	1946
All others				
Total	15,637.2	3,498.4	22	

[1] Includes administrative costs of extramural R. & D.
[2] Mainly the Advanced Research Projects Agency and other groups in the Office of the Secretary of Defense.

Source: "Federal Funds for Research, Development, and Other Scientific Activities, Fiscal Years 1969, 1970, and 1971," XIX (National Science Foundation, 1970), pp. 118-19.

As the Science Policy Committee of the American Association for the Advancement of Science (largely representing university science) and the Industrial Research Institute (representing a substantial sector of industrial research) have argued, government agencies must become more conscious of their impact on research and innovation.[6] They must develop "agency-specific strategies for science and technology" in order to advance the policy objectives for which they are responsible. This requires an exercise of leadership at the highest executive and agency levels which now does not exist. We will return to this subject in the conclusion of this report.

Thus far, what we have done as a nation is to undermine or eliminate the R and D mechanism which was geared to one set of national priorities, that of the Cold War. What we have yet to do is to refashion a new mechanism or system adapted to our new set of emerging civilian priorities: economic growth, export competitiveness, and social welfare. Certain measures such as the establishment of the Office of Technology Assessment and the Energy Research and Development Agency are steps in the right direction. But they do not constitute a national program or an adequate institutional mechanism to manage the nation's new set of needs. There is furthermore the grave danger that we may carry over into the future practices and attitudes from the past which will burden our effort to respond to these new needs. Yet, the nation's resources and potential in the area of R and D are sufficient to meet these new demands if they are properly managed and organized. In order to remedy this situation the next section of this report considers, what the government can and cannot do to improve technological innovation in the civilian industrial sector.

[6] These positions are produced in U.S. House of Representatives, Committee on Science and Astronautics, *Federal Policy, Plans and Organization for Science and Technology*, 93d, Cong., 2d. Sess., July 1974.

IV. WHAT WE KNOW (AND DON'T KNOW) ABOUT INDUSTRIAL INNOVATION

A national policy to foster and encourage a higher rate of technological innovation in the civilian industrial sector can be effective only insofar as it is consistent with and is based on what is known about the nature and process of innovation. Unfortunately, although economists have come to recognize the importance of innovation for economic growth, the economics of innovation is only in its infancy. There is very little reliable knowledge concerning the factors which tend either to facilitate or to retard technological innovation. What is known is highly tentative. In general, the findings of economists and others tell us what pitfalls to avoid rather than what should be done. Above all, what must be appreciated is that the primary factors which determine the tendency of a firm to innovate and for an innovation to be successful lie inside the firm and outside the reach of government policy. For this reason, the government can increase the technological opportunities and economic incentives to innovate (or to adopt more progressive technology) but it can do little more.

The one certain thing which economists do know is that there is a high correlation between the growth of industry sales and industry-financed R and D expenditures (Pavitt and Walker, 1974, p. 5).[7] While this observation may not be very useful, it does suggest that in the absence of a healthy rate of growth in a particular sector, government policies to stimulate innovation will have little chance of success. Beyond this relationship of sales growth and R and D activities, little is known with respect to the influence of competition, monopoly, patents, taxation, etc. on the propensity of firms to innovate and to adopt new technologies. With this reservation in mind, what is known about industrial innovation that can guide the formulation of government policy in this area?

The purpose of this section then is to identify those findings which are most relevant for determining what government can and cannot do to expedite technological innovation in the civilian industrial sector. Given the nature and character of industrial innovation as revealed by the research of economists, what aspects of the innovative process are amenable to government intervention and policy initiatives? What follows therefore is not meant to be a complete description and analysis of what is known about industrial innovation such as factors internal to the firm itself. The emphasis is rather upon the salient features of the innovative process which are most relevant for the concerns of this report.[8]

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[7] But even this observation must be qualified. Certainly it does not follow that the larger the sales the larger the commitment to R and D. Moreover, a declining market position may stimulate R and D in search for new markets and cost-reducing processes.

[8] This section relies heavily upon the original and synthetic scholarship of several British and American scholars who have been the true pioneers in the empirical and theoretical study of industrial innovation: George Eads, Christopher Freedman, Edwin Mansfield, Richard Nelson, Keith Pavitt, Merton Peck, F. M. Scherer, and Jacob Schmookler. Relevant writings are cited in the bibliography.

53-938—75——6

The Nature of the R and D Enterprise

The R and D enterprise consists of three types of activities. The first is *basic research* which leads to the generation of fundamental knowledge about nature. The locus of such research is usually the university and a relatively few government or industrial laboratories. The second is *applied research and exploratory development*, relating to specific applications. Carried out principally in engineering schools as well as government and industrial laboratories, this type of R and D can entail activities ranging from the testing of new processes to prototype and pilot plant development. And, thirdly, there is the *commercial innovation* of new processes and products. Such activities are usually conducted in industrial laboratories where economic and market criteria are the major determinant of R and D activities.

As one proceeds along this spectrum from basic research to commercial development, the relative importance of critical factors changes. At the basic research end of the spectrum costs are lowest and uncertainty is highest. According to a rule of thumb, the cost ratio of basic research, applied research, and commercial development is 1 to 10 to 100. Conversely, scientific and technological uncertainties are reduced (or at least should be) as one approaches commercial development. Moreover, as one goes from basic research to applied research to commercial development, the relevant criteria of program planning shift from scientific merit to technical feasibility to market demand.

Whereas basic research in universities and government laboratories tends to be wide-ranging and determined by "scientific" merit, industrial research and technological innovation are more focussed and keyed to markets. As it is the latter which is the central concern of this report, it is crucial that we understand the industrial firm's approach to innovation. In a succinct paragraph, this approach to strategy has been set forth by Nelson, Peck and Kalachek (1966) in their authoritative study as follows:

> . . . 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 process, 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.

Pavitt and Walker (1974) elaborate further:

> . . . decision making tends to be sequential, . . . and the key criteria in project evaluation change in importance as the project progresses. On the one hand, exploratory projects requiring few resources are decided between the researcher and his immediate supervisor, and the key criterion tends to be 'chance of technical success.' On the other hand, decisions involving large expenditures are made by the firm's top management after obtaining information from the firm's marketing, financial, manufacturing and R & D departments.

These contrasts and differences among the various types of R and D should be primary considerations in the development of a national policy toward R and D. They should determine the appropriate role of the various sectors of the R and D enterprise (university, government, and industry) and the locus of different types of decisions. Unfortunately, as shall be emphasized throughout this report, too frequently the comparative advantage of each sector has been neglected in the fashioning of national policy for R and D. With these considerations in mind let us look at the critical aspects of innovative process in industry and their implications for government policy.

The Coupling of Technological Innovation and Market Demand

For a long time, scientists and technologists, on the one hand, and economists, on the other, have argued over which is more important for successful innovation: the *supply* of new science and technology or the *demand* for new products and processes. At first, the best of the argument appeared to be on the side of the scientists and technologists who received support from the theories of Joseph Schumpeter (Schumpeter, 1950). According to this view, innovations arise outside the economic process; they are exogenous factors which come about due to the advance of science and technology. The supply of new knowledge and technological opportunities are said to be the main determinant of rapid and successful innovation (Schumpeter, 1950).

This view that innovation was outside the economic process and could not be explained by economic factors was challenged by the very detailed and painstaking researches of Jacob Schmookler. (Schmookler, 1966.) Schmookler demonstrated that the primary factor in successful innovation was market demand. The process of innovation was endogenous to economics and could be explained by factors. In effect, what Schmookler proved was the old saw that "necessity is the mother of invention."

There is support for both sides of this argument. On the one hand, scientific and technological advance open up new and unperceived possibilities. New technologies can create, if you will, their market. (Rosenberg, 1974.) Certainly this has been the case with such radical innovations as the computer, the laser, and nuclear power. On the other hand, many innovations such as many in the area of machine tools even today take place without the benefit of new science or technological capabilities. More importantly, many products such as synthetic rubber or pollution-control devices were called forth by economic or social needs. It was market demand which resulted in the new technologies.

The truth of the matter appears to be that successful innovation involves increasingly a *coupling* or *matching* of new science and technology with market demand. New knowledge and economic need, to use Schmookler's analogy, are like the blades of a pair of scissors. They must be brought together or coupled by far-sighted and resourceful entrepreneurs if successful innovation is to result. As Freeman has put it, "necessity may be the mother of invention, but procreation still requires a partner." (Freeman, 1974.)

The institutional response to this increasing need to couple new knowledge and market needs has been the professionalization of R and D in industrial firms. The growing complexity of technology, the increased scale of processes, and the specialization of scientific/technical work make professional R and D capacity an increasing necessity for an industry. (Freeman, 1974, p. 33.)

The purpose of such R and D capabilities in the corporation is to develop new products and processes but also and, of perhaps greater importance, to monitor external scientific and technical advances which might be of relevance to corporate planning. As many studies have shown, much of the knowledge of importance for technological innovation is obtained from outside the firm. (See, for example, Myers and Marquis, 1969.) These external sources include universities, government laboratories, and other industries. What this suggests of course is that industrial firms can not be depended upon to provide all the knowledge they require to be innovative despite the increasing emphasis upon in-house professional R and D capacities.

A critical factor in this diffusion and absorption by the firm of outside scientific and technical knowledge is that this transfer is predominantly "person-embodied." (Pavitt and Wald, 1971.) Through conferences, person-to-person communications, and the movement of individuals from one institution to another, knowledge is transferred throughout the economy. What this means, therefore, is that a firm and a nation must have scientists and engineers who are contributing numbers of a scientific or technological community if the firm or nation is to remain abreast of scientific and technological developments. It is for this reason that the more progressive firms such as Bell Laboratories or IBM maintain a strong basic research capacity even though the scientists may seemingly contribute little directly to technological innovation.

As Freeman points out (Freeman, 1964, pp. 168–69), there are three important implications of coupling novel ideas and market needs. In the first place, an innovative firm must increasingly have an in-house capacity to monitor and, if possible, particpate in the advance of science and technology if it is to convert new knowledge into a competitive advantage. Secondly, the firm must stay in close touch with the requirements of its customers and the needs of the market. And, thirdly, the test of successful entrepreneurship is to link or couple technical and market possibilities. Despite its many imperfections, the modern capitalist corporation is undoubtedly the most successful institution we have for coupling new knowledge and market demand in order to achieve successful innovation.

The importance of the coupling phenomenon for successful industrial innovation has at least three significant implications for government policy. First, although the government agencies may develop superior capabilities in scientific research and technological development, they are less apt to have a sense of market needs and potential. Secondly, the government's comparative advantage lies in advancing science and technology up to the point of commercial development where market considerations become of cardinal importance. And, thirdly, the government can play an important role in certain types of innovation through the provision of a guaranteed market for industry. But it should leave to private industry the responsibility for coupling government requirements with available technological possibilities.

This emphasis upon market demand as a stimulant to innovation must be qualified with respect to innovation in one area of economic goods, that is consumer goods and services. Outside the military and space areas, most industrial R and D is in the area of capital goods and intermediate products, e.g. chemicals and other materials (Freeman, p. 298). Consumer industries, however, tend to underinvest in R and D; they are less likely to undertake R and D projects which lead to radical innovations. What relatively little R and D they do is too frequently used for marginal product differentiation, annual model changes, and activities related to planned obsolescence, resulting in a costly burden to the economy and lower social welfare payoff. Moreover, in contrast to the military, capital goods, and intermediate goods sectors where the user usually knows what he wants and can evaluate what he gets, in the consumer goods sector the consumer is too frequently unable to specify his wants and evaluate what he gets. What this suggests, therefore, is the need for the government to evaluate more systematically than it presently does the impact of government policies and regulations on the production of consumer goods and services.[9]

In conclusion, two aspects of industrial innovation are of decisive importance for government policy. The first is the fact that the magnitude and direction of industrial innovation are in general sensitive to market and production demands. The second is that market uncertainty and the high risk of failure surround and condition the innovative process. For these reasons, the government can influence both the pace and direction of industrial innovation most effectively through its influence on industrial, consumer, and public service demands. (Pavitt and Walker, 1974, p. 4.)

The emphasis of both direct and indirect government intervention in the economy should be to transform the market in ways which will encourage industry to innovate products of better quality and greater social utility. The government, however, should not substitute its judgment for that of industry concerning how these demands are to be met. But it should create the incentives and disincentives which will encourage industries to be more innovative in the use of their R and D resources. Thus, in the area of energy, the government should not decide whether this or that particular technology should be commercially developed but it should set standards and create incentives which encourage the efforts of industry in one direction or another. In short, through its regulatory and other policies, the government could do much more to encourage socially useful technological innovation.

The Critical Importance of Uncertainty

The most critical aspect of industrial innovation is that of uncertainty. The simple fact is that innovation is very risky. Most attempted innovations fail, and obviously the more radical the innovation the higher the probability of failure. The conventional wisdom of R and D managers is a success rate of 1 in 10 or even 1 in 100. (Freeman, 1974, p. 222.) While the probability of failure decreases as one proceeds along the spectrum from basic research to commercial development, the rate is still high at the product stage. According to a study by Edwin Mansfield, for every 100 projects that were begun, 57 were completed technically, 31 of this number were commer-

[9] This criticism of the consumer goods industry may be relevant with respect to the fact that the United States has a major trade deficit in this area. (See Table 2.)

cialized, and only 12 of the 31 were market successes. (Mansfield, 1971.)

As Freeman has pointed out, there are three types of uncertainties which cause innovations to fail: general business uncertainty, technical uncertainty, and market uncertainty. (Freeman, 1974, p. 223.) The first of course refers to the state of the economy and perhaps little need be said about it. Technical uncertainty is partly a matter of whether or not a specific innovation "works." This type of uncertainty can be reduced by experimental development or prototype testing. But even in the case of such a well-managed innovation as Du Pont's Corfam, failure can take place after commercial launch. Moreover, technical uncertainty is more than a matter of working or not working. It is a matter of standards of performance under varying conditions and at particular costs. (Freeman, 1974, p. 224.) For example, the French-British supersonic commercial aircraft, Concorde, is technologically highly successful, but its performance characteristics and high cost have greatly diminished its commercial attractiveness. The cost overrun of the Concorde is many times its original cost and its performance characteristics have greatly deteriorated. In short, whether or not an innovation "works" is not enough to determine "technical feasibility."

Market uncertainty is a far greater problem than technical uncertainty. Contrary to Galbraith's argument that large oligopolistic corporations can create the markets for new products, market demand despite consumer analysis and advertising remains difficult outside a few areas such as the military, capital goods, and the intermediate goods market. Market demand projections have been grossly inaccurate. The overriding tendency is to be extremely optimistic. How else is it possible to sell risky innovations to the board of directors, a government funding agency, or a congressional committee.

As a consequence of the high degree of uncertainty surrounding innovation, industrial firms have a strong incentive not to undertake radical innovations. Instead they prefer to concentrate their R and D resources on defensive innovations, imitative innovation, product differentiation, and process innovations. That is to say, they prefer to defend their market position through imitating the innovations of competitors or through cost-reducing improvements in industrial production. This conservative nature of firms with respect to new product development has also been a factor in the overseas expansion of American corporations. The safer course for the firm has been to expand production abroad of older products rather than to innovate new products for the home market. (Gilpin, 1973.)

Given the large technical and market uncertainties surrounding innovation, the tendency of most firms is to concentrate on short-term, low-risk projects. Their approach is to protect themselves against untoward developments rather than promote radical departures. The firms which do accept a high degree of uncertainty and risk radical innovations tend to be small firms trying to break into a market or larger firms with a portfolio of projects ranging from safe to a few "high risk" ventures. Or, the firm will undertake radical innovations because of government funding and/or a guaranteed market. (Freeman, 1974.) In general, however, the high risk and uncertainty surrounding innovation, especially radical innovation, mean that industry tends to underinvest in long-term research and innovation.

The consensus among students of industrial innovation is that the high degree of uncertainty and high rate of failure attending industrial innovation can not be eliminated. In the view of Freeman, innovation is a "higgledy-piggledy" world where the economists' rational models of firm behavior do not seem to apply or help us very much in understanding or predicting successful innovation. It is a largely trial and mostly error process. Better management, project selection, and cost/benefit techniques may reduce uncertainty and failures somewhat, but the probability of failure will remain high. While applied research and experimental development may reduce technical uncertainties, there remains the greater obstacle of market uncertainties. The irreducible fact of uncertainty is the most salient feature of industrial innovation and of greatest relevance for determining what government can and cannot do to foster technological innovation in industry. In conclusion, it should be noted that socialist governments, with their control over the market have been no more, and in fact, less, successful than free economies in overcoming the problem of uncertainty.

SIZE OF FIRM, COMPETITION, AND THE PROPENSITY TO INNOVATE

Another issue which has engaged the attention of students of technological innovation is whether large or small firms tend to be more innovative. The argument in favor of large firms was initially set forth by Schumpeter who argued that only large oligopolistic corporations had the resources and incentive to innovate. Firms in an oligopolistic industry had less fear of imitation by competitors and loss of their product monopoly with a subsequent decline of profitability. They were thereby more likely than smaller firms in a competitive situation to capture the returns on their initial investment in innovation. (Schumpeter, 1950, p. 106.) Moreover, the large firms are said to have advantages of greater resources, economies of scale, product diversification, and a greater willingness to take chances. (Scherer, 1970, pp. 353–54).

This defense of bigness was challenged by Jewkes and collaborators in a very detailed study of the sources of invention. (Jewkes, et al., 1969.) Jewkes was able to show that individuals and small firms in a competitive industry had a higher propensity to invent than large firms. In contrast to the rugged individualism and daring of the private entrepreneur, large corporations tend to be overly conservative. The scale of the organization itself makes the coupling of new knowledge and market demand difficult. In a number of areas—especially scientific instruments, machinery, and electronics—small firms such as those identified with the Route 128 and Santa Clara county phenomena tend to predominate as innovators.[10] Frequently, the small firm makes the important innovations which are then picked up and marketed by large firms. This has been the case, for example, in the area of computers and electronic data processing. When large scale capital investments are required, however, small scale firms tend to be at a disadvantage. Yet, the large firm may use these resources to suppress innovation and prevent the entry into the market of small firms with radical innovations.

[10] On Santa Clara Country's innovative, science-based small companies, see, "California's Great Breeding Ground for Industry," *Fortune*, June 1974.

Although Jewkes' analysis is a necessary correction to Schumpeter's argument, it too is flawed. In the first place, Jewkes failed to make a distinction between invention and innovation, that is, the distinction between a novel technology and its ultimate success in the market. While the small firm, as Jewkes shows, may be more inventive than the large corporation, successful innovation requires large production, financial, and marketing resources. Most of the cost in fact is at this end of the innovative process. For this reason, the big firm may be better able than the small firm to couple invention and market. Furthermore, the increasing professionalization and cost of R and D tend to favor the big firms. As a consequence, as scientific and technical tadvance become more and more the basis of industrial innovation large firms will tend to have a greater innovative propensity over small firms. In important areas such as chemicals and heavy machinery, for example, small firms are excluded for reasons of size. In industry as a whole and in all countries most R and D is performed by large firms. (See Tables 7 and 8.)

TABLE 7.—PERCENTAGE OF TOTAL INDUSTRIAL R. & D. PERFORMED IN FIRMS RANKED BY SIZE OF R. & D PROGRAMS

Country	Number of firms ranked by size						
	4	8	20	40	100	200	300
United States	22.0	35.0	57.0	70.0	82.0	89.0	92.0
United Kingdom	25.6	34.0	47.3	57.9	69.5	75.0	77.0
France	20.9	30.5	47.7	63.4	81.0	91.2	95.6
Japan				[1] 47.7	[2] 52.1	[3] 63.1	[4] 71.4
Italy	46.4	56.3	70.4	81.6	92.5		
Canada [5]	30.3	40.8	58.4	71.5	86.2	93.2	
Netherlands	[6] 64.4						
Sweden	33.2	43.0	54.0	71.0	85.4	90.0	
Belgium	38.5	51.8	72.6	82.7	92.8	97.5	99.4
Norway	29.5	38.8	55.7	70.6	88.2	97.9	100.0
Spain	25.2	47.0	73.9	91.5			

[1] The 1st 54 firms.
[2] The 1st 85 firms.
[3] The 1st 180 firms.
[4] The 1st 289 firms.
[5] Current intramural expenditure.
[6] The 1st 5 firms.

Source: OECD (1967). (Reproduced from Freeman, 1974, p. 200.)

TABLE 8.—FUNDS FOR R. & D. PERFORMANCE BY SIZE OF COMPANY AND SIZE OF R. & D. PROGRAM, UNITED STATES, 1970

[Share of funds by millions of dollars]

Firm size by total employment	Total	Program size in thousands				
		Less than $200	$200 to $999	$1,000 to $9,999	$10,000 to $99,999	More than $100,000
Less than 1,000	799	209	135	298	157	
1,000 to 4,999	1,091	27	117	550	397	
5,000 to 9,999	1,077	2	29	376	670	
10,000 or more	14,890	1	11	597	3,524	10,757
All firms	17,857	239	292	1,821	4,748	10,757

Source: National Science Foundation (1972, table 6). (Reproduced from Freeman, 1974, p. 201.)

The available evidence does not overwhelming favor either the proponents of big or small firms, although the changing nature of the R and D enterprise and its relationship to innovation may be on the side of the large firm. Yet, Xerox, IBM, and Polaroid were once small firms. They grew large precisely because they were research-intensive. Moreover, while there may be a threshold size which is necessary to support a sufficiently large R and D capability, it does not follow that the larger the firm and size of sales the larger the size and effectiveness of the R and D program. The relationship between firm size and commitment to R and D is not linear or proportional. On the contrary, except for the chemical industry, large size may be a detrimental factor. As Scherer concludes, among the 400 or so largest U.S. firms,

> . . . giant scale has a slight to moderate stultifying effect. . . . All things considered, the most favourable industrial environment for rapid technological progress would appear to be a firm distribution which includes a preponderance of companies with sales below $200 million, pressed on one side by a horde of small, technology-oriented enterprises bubbling over with bright new ideas and on the other by a few larger corporations with the capacity to undertake exceptionally ambitious developments. (Scherer, 1970, pp. 361–62.)

In summary, if the researches of economists do not support the argument that small firms are more innovative and should be favored by government, neither do they support the argument of Schumpeter, Galbraith, and others that industrial concentration enhances innovative potential. Moreover, industrial sectors and types of products differ with respect to the importance of size for the propensity to innovate. In short, while there may be good social, political, or economic reasons to favor corporate concentration or decentralization, the issue of corporate size as related to government policy to encourage industrial innovation, remains an open question.

With respect to the effect of monopoly, oligopoly, and competition on the propensity to innovate, the researches of economists are contradictory and point to no firm conclusions. At one extreme, the existence of monopoly tends to inhibit innovation. The monopolist usually has little incentive to introduce new products which undermine existing products. At the other extreme, too much competition and the inability of a firm to capture or internalize the benefits of innovation can also be inhibiting. These arguments point to the conclusion that some degree of oligopoly may be most conducive to innovation. But beyond this it is difficult to determine what an optimum number of competing firms might be.

> The main lesson to be drawn from a review of the qualitative evidence is that no simple, one-to-one relationship between market structure and technological progressiveness is discernible. Indeed, it seems reasonable to infer that market structure has less influence on the pace at which innovation occurs than certain other variables. (Scherer, 1970, p. 371.)

However, a major factor stimulating innovation in an industrial sector is the entry of new firms with radical innovations. Examples of entrants introducing innovations that established firms failed to develop or actually suppressed are legend: the incandescent lamp (Edison), the electric typewriter (IBM), the transitor radio (Sony). The importance of new entrants has been summarized by one authority in the following words:

> . . . the major economic force leading to innovation is not any particular structural form in the industry, but the conditions regarding entry to that industry . . . . Where the entry of significant competitors is possible, innovation will be much faster. (Sturmey, 1958, p. 277.)

53-938—75——7

An entry is largely a function of new scientific and technological possibilities, the government can encourage a more rapid rate of innovation through financing the expansion of scientific knowledge and technical opportunities.

Beyond this minimum function, as Freeman argues, government policy must do two things. In the first place, it must permit and encourage the formation and growth of innovative small firms. As recent experience suggests, many of our most radical and important innovations begin with the inventor-entrepreneur. But, secondly, the importance of large firms with large professional R and D capacities must be appreciated. Only these firms have the resources to manage the cost and scale of many types of innovation today from aircraft to computers to turbo-generators and nuclear reactors. A national strategy for R and D, therefore, must have room for both the dynamic small firm and the large firm strongly endowed with R and D resources. (Freeman, 1974, pp. 218–21.)

The Role and Importance of Basic Research

A much-debated topic among students of technological innovation has been the importance of basic science: Does scientific research, as contrasted to technological knowledge, contribute anything to successful innovation? The skeptical position was stated most emphatically by former Secretary of Defense Charles Wilson when he defended cutbacks in the Pentagon's budget for basic science with the argument that he was not interested in why potatoes turn brown or grass is green. Several empirical studies including one which became an anathema to the scientific community—the Department of Defense's Project Hindsight—have supported this viewpoint that basic scientific research contributes little to technological innovation. (Sherwin and Isenson, 1966.)

More reliable studies have concluded that scientific research contributes to technological innovation. Studies by the Battelle Memorial Institute and the Illinois Institute of Technology have found that basic research in particular areas is of decisive and critical importance. However, the lead-time between the basic scientific findings and the technological innovation may be a matter of several years or decades. In the research-intensive and high-technology sectors of the American economy, the monitoring and utilization of basic knowledge are of great importance to the firm's innovative capacity. (See Battelle, 1973 and Illinois Institute of Technology 1969.)

The findings of academic, industry, and government studies with respect to the important role of basic science for technological innovation have been summarized by two authorities in the following paragraphs:

1. Although the discovery of new knowledge is not the typical *starting point* [my italics] for the innovative process, very frequently interaction with new knowledge or with persons actively engaged in scientific research is essential.

2. Innovation typically depends on information for which the requirement cannot be anticipated in definitive terms and therefore cannot be programmed in advance: instead key information is often provided through unrelated research. The process is facilitated by a great deal of freedom and flexibility in communication across organizational, geographical and disciplinary lines.

3. The function of basic research in the innovative process can often be described as meaningful dialogue between the sceintific and technological communities. The

entrepreneurs for the innovative process usually belong to the latter sector, while the persons initimately familiar with the necessary scientific understanding are often part of the former. (Price and Bass, 1969, p. 804.)

In general, it is the larger firms which tend to utilize basic science. Through their own in-house R and D capabilities, participation in conferences, and use of academic consultants, they monitor and keep themselves abreast of scientific developments at the major universities. This flow of basic science findings into industry is usually at the initiative of industry and takes the form of "person embodied" knowledge rather than through scientific technical journals. Outside a few science-based areas such as scientific instruments and electronics, small firms appear to lack the necessary resources and to be unappreciative of the importance of basic science. As in the case of agriculture, the small scale of firms in many traditional industrial sectors would appear to call for specific government policies and institutions to foster a greater utilization of new technical and scientific knowledge.

Unfortunately, despite the importance of basic research a sort of Gresham's law operates in the area of government funding for science and technology: applied research tends to drive out basic research. It is so much easier to defend projects when one can point to specific objectives and concrete outcomes. By its long-term and unpredictable nature, basic research is greatly disadvantaged in the struggle over budget priorities. Therefore, there is the grave danger that in a period of severe budget constraint, basic research will be sacrificed and the pool of basic knowledge will slowly dry up. To prevent this from happening is a major responsibility of government.

TAXATION, PATENT AND REGULATORY POLICIES [11]

As remarkable as it may seem, the impact of taxation, patent and other government policies on industrial innovation is unclear. This subject has received very little attention by economists and other students of innovation. Obviously a tax policy which gives firms a high level of retained earnings or permits a deduction or write-off for R and D expenditures may encourage a higher rate of R and D. But the risk and uncertainties surrounding innovation, especially radical innovation, are far more important considerations. The tendency of the firm is to employ retained earnings and tax-deductable funds in low-risk areas. It is where a high rate of retained earnings represents an expanding market that a firm is encouraged to assume the cost and risk of innovation. For these reasons, there is little evidence to suggest that government manipulation of tax policies by itself would encourage a higher rate of industrial innovation.

With respect to patents, the Constitution recognizes that an inventor's rights should be protected if there is to be an incentive to invent. Yet, the importance of patents differs greatly for different industrial sectors. In certain of the most innovative sectors such as chemicals and in process technology, there is actually a tendency not to file a patent lest a competitor thereby acquire design or other technical information. Because of the differing role of patents in different industrial sectors, there appear to be few generalizations one can

[11] For a survey of these policies see OECD, *The Conditions for Success in Technological Innovation*, Paris 1971; and OECD, *United States Industrial Policies*, 1970.

make on the effects of patents on innovation. More importantly, patent policy like tax policy is far less important than the capacity of firms to couple new knowledge and market demand.

This is not to argue, however, that the patent system could not be improved. Although patent protection can be defended as providing an incentive to innovate, it can be used (and frequently is) as a means to suppress innovation and competition. Large firms in particular can and do use their vast R and D resources to acquire and maintain a monopoly position in an industrial or product sector. Patents can thereby be used to erect barriers to entry against more innovative smaller firms and to prevent the diffusion of innovations throughout the economy. For these and other reasons, many reforms have been proposed. (Scherer, 1970, pp. 394–99.) But the controversy these reforms engender, the slim prospects for significant reform, and the difficulty of reconciling the interests of the innovator with those of society force one to conclude with Jewkes and colleagues that "it is almost impossible to conceive of any existing social institution so faulty in so many ways. It survives only because there seems to be nothing better." (Jewkes, et al., 1969, p. 253.)

Lastly, government regulatory policy can and does have an immense impact on the rate and direction of industrial innovation. However, these policies and regulations tend to be industry-specific and operate in a crosscutting and contradictory way. (Eads, 1973.) As a consequence we know very little about the net effect of these policies on specific industrial sectors. What we do know from the few industrial sectors which have been examined is that government policies of one sort or another inadvertently have an important impact on commercial innovation.[12] What we need therefore is greater attention given to the impact of government regulatory and other policies on commercial innovation in specific industrial sectors. The need, therefore, is for government regulatory agencies to become more conscious of the impact of regulations on the innovative behavior of the firms they regulate. We return to this subject in the conclusion of this report.

The Question of Venture or Risk Capital

All innovation requires an increasingly greater capital investment at each succeeding stage in the innovative process from R and D to the commercial launching of a new product or process. The acquisition of such venture or risk capital has always been a serious problem for the individual or corporate entrepreneur. By definition, innovation is risky. The more innovative the process or product, the more risky and more difficult to find funding. For this reason, most venture capital comes out of the firm's retained earnings or from government contracts.

The increasing demands for capital to finance energy development, to overcome the materials shortage and a host of other major social and economic needs has produced what is commonly called a "capital gap." These pressing needs and the general decline of corporate retained earnings, it can be argued, have accentuated the problem of sufficient venture or risk capital to finance innovation in American

[12] For the case of commercial aviation, See Ronald Miller and David Sawers, *The Technical Development of Modern Aviation* (New York: Praeger Publishers, 1970). Also Almarin Phillips, *Technology and Market Structure* (Lexington, Massachusetts: D. C. Heath and Co., 1971).

society. These capital needs have led to a host of proposals ranging from credit rationing through the Federal Reserve System to the reestablishment of the New Deal's National Recovery Administration (NRA).

There are two aspects of this subject which must be kept separate in any analysis. The first is the amount of investment capital generated by private and corporate savings. The second is the distribution of this stock of capital among different economic sectors. Proposals for government programs to finance innovation or for refashioning the capital market in order to provide greater financing of innovation frequently fail to make this critical distinction.

According to what economists have dubbed "Denison's law," there is a "remarkable stability of the rates of gross private saving to gross national product in the United States. . . ." [13] The ratio of gross savings to GNP has changed little over the period 1929 to 1960. For this reason, proposals for greater government financing of commercial innovation would appear to have the effect of transferring capital from the private to the public sector. They do not generate or create additional capital but through taxation or the selling of government securities, they decrease the amount of investment capital in the private sector. In other words, a proposal like the reestablishment of the NRA would merely shift the locus of decision with respect to investment decisions rather than create additional capital.

From the perspective of fostering innovation, this transfer of investment capital from the private sector to the government can be justified only if it can be shown that the government is more competent than corporations or banks in making investment decisions. Regrettably, the available evidence suggests the opposite. Except where government requirements are involved (for example, military technology), government agencies are too removed from the market to make wise investment decisions. The experience of France, Great Britain, and this country suggests that investment decisions will be largely dictated by political or prestige factors rather than economic criteria. The British-French financing of Concorde and the French nuclear reactor program are cases in point. A government program to supply venture capital to private corporations would run a great risk of becoming a lender of last resort to inefficient and bankrupt large corporations.

In order to prevent these dangers, it has been suggested that the government participate as a partner with private enterprise in the development of commercial innovations, Both the government and the private sector would share the risk and put up part of the funds. Presumably the private sector would not put up its share unless the prospects of commercial success were good; the public would thereby be protected from the dangers of subsidizing inefficient firms or of financing highly dubious commercial ventures. This at least is the rationale which underlies British and French programs of government participation in funding commercial innovation. Under the terms of these programs, if the project is successful the government loan is repaid. If the project fails, the loan is forgiven. Unfortunately, these programs have been on the whole quite unsuccessful.

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[13] David Paul and John L. Scadding, "Private Savings: Ultrarationality, Aggregation and 'Denison's Law,' " *Journal of Political Economy*, Vol. 82, No. 2, Part I, March/April 1974, p. 227.

One must ask the following question about such joint-venture programs: If the project is a good commercial risk and the private sector is willing to put up at least part of the venture capital, why is there need for government financial participation in the first place? The usual rejoinder is that the scale of the project is too large for the private sector. As we argue in another section of this report, the "scale of technology" argument for government financing of commercial developments is a highly dubious one. In short, there is little evidence for and much against the argument that the government should become a supplier of venture capital.

The second relevant issue is that of the distribution of investment capital. It can be argued that there is sufficient investment capital but that biases or imperfections in the capital market cause this capital to be distributed among different sectors in an inefficeint or socially undesirable manner. For example, the trust departments of large banks which hold a large fraction of our total investment capital tend to prefer the purchase of equities in certain so-called "blue chip" corporations (cosmetics, leisure, etc.) rather than in more basic corporations (steel, machine tools, etc.). Thus, it can be argued, the basic industrial sector upon which our long-term prosperity rests is denied the capital it requires to grow.

The solution put forth to this problem of the maldistribution of capital is that of credit rationing which can take many forms. (Jaffee and Modigliani, 1969.) Through different sets of incentives or disincentives, the government could seek to redirect the flow of credit into industrial sectors considered to be of higher priority than those presently favored by capital markets. Or, as in the case of the Small Business Administration, government policy might favor a particular type of business.

The case for credit rationing may very well be a strong one in American society today. Underinvestment in high priority sectors (housing, energy, and mass transportation) may justify government measures which increase the flow into these areas. It is extremely difficult, however, to justify credit rationing on the basis of accelerating technological innovation. In the first place, to do so would necessitate the identification of particular industrial sectors or types of firms which were failing to innovate because they lacked venture capital. While it is possible to identify individual firms with a promising conception which failed to receive financing, it is difficult to generalize and argue that the capital market operates against particular sectors or firms with a high propensity to innovate. For example, government policies which favor small business may be justified on the grounds that small business is socially desirable and is discriminated against in the capital market. But, as we have argued above, small business cannot be favored on the grounds it has a higher propensity than big business to innovate. Additionally, it is highly unlikely that credit rationing would force banks and other credit institutions to loan funds to risky projects that they would not finance in the absence of credit rationing. The effect of credit rationing in fact might well be to encourage credit institutions to favor the least risky projects and discriminate against the more innovative firms. (Jaffee and Modigliani, 1969.)

Although credit rationing cannot be justified on the basis of the argument that certain types of firms with a high propensity to innovate have difficulty acquiring venture capital, credit rationing could indirectly have a significant effect on technological innovation. As we have already seen, the propensity to innovate in a particular sector is primarily a function of economic growth and market demand. Therefore, if credit rationing or other government policies stimulate growth or demand in a particular sector (energy, construction, transportation, and so forth) the effect would undoubtedly be a higher rate of innovation in that particular sector. The fundamental question, however, is one of national priorities with respect to sectors rather than technological innovation for its own sake. Therefore, the decision whether or not to ration credit must be made on grounds other than that of technological innovation.

Innovative Versus Imitative Strategies

Another issue which pervades the literature is that of the relative merits of an innovative or an imitative strategy for either a firm or for a nation. On the one hand, there are those who argue that the United States must maintain technical and market leadership through being ahead of other nations in the introduction of new products and production processes. Or, if this is impossible, at least the United States must have the capacity to defend itself in case other nations make a technological breakthrough. In this latter case, the United States would seek to recoup its position through the innovation of a better product or process.

In opposition to this view that the United States must be "first," there are those economists who argue for an imitative strategy. (Levitt, 1961.) What these individuals emphasize is the risk and cost of the innovative strategy. The effort to be first spreads scarce R and D resources across too broad a front and decreases their effectiveness. Moreover, what is really critical in innovative success is the capacity to evaluate markets. Herein, they would argue, lies the success of the Japanese. Rather than expend large resources on innovative R and D, the Japanese have used their vast R and D capabilities to absorb and adapt the innovations of others. Their skill has been one of coupling the innovations of others with their own perception of potential markets.

This criticism of an overemphasis on innovation is well taken. Innovation is an international process from which the United States derives great benefit and from which it should not shut itself off. Many of the most important innovations upon which American export success has been based were made abroad: jet aircraft and certain petro-chemicals, for example. American success lay in perfecting these technologies, production, and marketing. Moreover, a major factor in the development of new products and increased productivity is the improvement of intermediate products by suppliers of new machinery or materials. For example, synthetic fibres were developed by the chemical industry, not the textile firms. Too frequently the overemphasis on indigenous technology and the desire to be first in all things has led the United States to develop inferior new products and forego superior technologies developed abroad. In short, the adoption of innovations made outside the United States or the firm can be a major source of new products and processes.

Despite these reservations concerning an overemphasis on innovation, there is justification for concern over the status of America's capacity to innovate new products and processes. In the first place, America's comparative advantage has been and will remain its ability to innovate. We grow and compete through the innovation of new products and production processes. Given our high wage rates and standard of living it could not be otherwise. Secondly, while the United States must and will continue to absorb foreign technologies, the United States cannot depend upon this flow for the technologies it requires. A large fraction of the world's technology has been generated by the United States due to the nature of our market and scientific-technical resources. If we don't continue to generate the technology we need, it probably won't be generated elsewhere. And, thirdly, there is a danger inherent in overdependence upon foreign technology. The relatively free flow of technology which has characterized the past several decades may not continue into the future; this is a possibility that greatly concerns the Japanese and is forcing them toward a more innovative strategy. At the least, if one is to acquire foreign technology, one must have technology with which to bargain and trade.

In addition to these considerations, the effect of inflation has accentuated the tendency of corporations to invest scarce R and D resources on short-term goals. With declining profit margins and rising costs, the tendency of firms is to cut back on R and D expenditures, especially the more risky type of innovations. Thus, at a time when increasing international competition calls for increasing innovation, the tendency of individual firms is to cut back. For this reason, the government must assume a greater responsibility for stimulating an adequate level of expenditure on scientific research and technological innovation. The danger which faces us in the future is not a tendency to overemphasize but to underemphasize innovation. But when promising foreign innovations present themselves the United States must be willing to adopt them rather than seek to be first and independent in all things.

Obviously the correct approach is a mixture of both innovation and imitation. Innovation is not an end itself; imitation of foreign developments in particular cases may be the more appropriate means to new products and greater efficiency. But the United States cannot do like the Japanese and follow an imitation strategy. In the last analysis, the decision must be left up to individual firms to follow one strategy or another. But it is the responsibility of the government to ensure that American scientific and technological capabilities make innovation an attractive possibility. Moreover, the measures recommended in this report by which to improve industrial innovation within firms are also ones which will encourage a higher rate of diffusion and absorption of innovation from outside the firm or from abroad.

What, then, are the implications of this analysis of technological innovation for government policy? The answer to this question is the subject of the next section of this report.

V. WHAT THE GOVERNMENT SHOULD AND SHOULD NOT DO

This portion of the report is divided into three sections. The first part analyzes the reasons which justify government funding of scientific research and experimental development. The second part argues that, despite elaborate and sophisticated arguments to the contrary, there are certain things with respect to R and D that government does poorly and should not do. And, finally, the third part briefly considers Project Independence and the energy R and D program from the perspective of what government can and should not do. Throughout this analysis, the report draws heavily upon the researches of the several economists who have made major contributions to our understanding of technological innovation.

Justifiable Reasons for Government Funding of R and D

The basic argument for government financing of R and D is that certain market imperfections exist which result in a non-optimum level of private resources devoted to overall R and D or to specific economic sectors. In other words, for various reasons, there is an under-investment of private (university, industry, or agriculture) resources in R and D. These reasons usually involve the structure of the industry itself or a divergence between private and social interests. Among these reasons the more important ones are the following:

(1) *The Public Nature of Knowledge*

By its very nature, basic and certain types of applied research involve a very high degree of uncertainty both with respect to its results and its utility. Moreover, as the results of basic research and most applied research are made public, a firm cannot capture the results of its investment. Business corporations therefore have little incentive to invest heavily in basic and even applied research. Aside from a few high technology corporations, a firm's primary purpose in conducting scientific research is to monitor basic research conducted in university and government laboratories. For this reason, most basic science is carried out by universities and is financed by the government.

While few would deny this responsibility of the government to fund basic research in science and technology, the tendency is to under-invest in basic science and technology. The desire for short-term and immediate payoff tends to predominate over the long-term need to increase the pool of knowledge. Frequently, this deemphasis on basic science is justified on the grounds we have too much knowledge already and the task at hand is to apply what we have. While there is some basis for this judgment since a lot of money has gone into big science projects (costly particle accelerators, for example) and too many scientists have been diverted away from the needs of society, the surfeit of knowledge argument is fallacious. Though our pool of knowledge is greater than at any time in the past, our need for scientific and technical knowledge is even greater. The proper measure of comparison is our present pool of knowledge set against the sea of ignorance which surrounds it. In terms of what we need to know, our knowledge is really very small.

(2) *Structural Aspects of Industry*

A second set of reasons for under-investment in both basic and applied research as well as in experimental development relates to the structural characteristics of industry. Oligopolistic industries, for example, may concentrate their resources on short-term improvments in existing products rather than in more risky and market-disturbing long-term innovations. (Pavitt, 1974). Other firms due to technical, managerial, or organizational limitations may fail to appreciate the potential benefits of R and D. (Pavitt and Wald, 1971.) In certain critical industries such as housing, agriculture, and machine tools, the size of the firm or operation is too small and the industry is too fragmented to support an adequate research effort. Lastly, technical and market uncertainties may inhibit firms from investing in longer-term, radical innovations. The incentives in industry are biased in favor of short-term goals rather than the development of radical innovations. (Freeman, 1974, p. 309.)

(3) *Social and Political Needs*

A third category of reasons for government financing of R and D relate to society's social and political needs which cannot be met by the market mechanism or, at least, by the market mechanism unaided and influenced by government policies. In addition to military-related technologies, the government may finance R and D in high technology or politically sensitive areas for security of supply reasons. Atomic energy, aerospace, and electronics have largely been supported by the government due to their critical importance for a modern industrial system. With the launching of Project Independence, security of supply considerations have now been extended to many newer areas of energy production and conservation.

Other social and political reasons for government support of R and D include buyer protection in consumer goods (pharmaceuticals, food, transport, etc.). In other cases, government supported R and D may be justified in order to assess the external or social costs of new technology. Such technological assessment studies are carried out with respect to pollution, safety, public health, etc.

These considerations add up to the argument advanced by Eads and Nelson that in addition to basic research, government has an important role in financing scientific and technical activities when certain conditions exist. For various structural or financial reasons, the private sector may not be able to put a technology on a sound scientific basis thus requiring government financing of basic and applied research. At a more advanced level, industry may be unable to finance exploratory development activities and the testing of new products and processes. Additionally, market conditions may retard the development of a technology needed for social or political reasons.

What must be emphasized, however, is that the role of the government should be restricted to applied research and exploratory development. Contrary to the "scale argument," (see below) the role of the government should not extend to costly commercial developments. As applied research and exploratory development are less expensive the government should spread its resources across a broad front. As Pavitt has emphasized, the government programs in support of R and D "should be managed on an incremental, step-by-step basis, with the purpose of reducing key scientific and technical uncertainties to a degree that private firms can use the resulting knowledge to decide when (with their own money) they should move into full-scale commercial development." (Pavitt, p. 21.)

As Eads and Nelson point out, this approach is the one that has been so successfully followed by the Department of Agriculture, the former National Advisory Committee on Aeronautics, and by the Atomic Energy Commission in the 1950's. In each of these areas the role of the government has been justified by such factors as the structure of the industry (agriculture), the need for exploratory research to reduce uncertainties, or the slow pace of the private sector in developing socially needed technology. In each of these examples, institutional mechanisms have facilitated cooperation among government, university, and academic laboratories with one important exception. In none of these areas has the government attempted to finance commercial developments or undertaken the role of entrepreneur. The two major exceptions are the breeder reactor and the aborted SST.

The writer of this report believes that those reasons for government support of R and D already discussed, such as the nature of R and D itself or structural problems of industry, legitimatize government support. For example, the public nature of scientific discoveries and the fragmented nature of agriculture necessitate an important funding role for the government. The role of the government must be to support long-term, high-risk R and D, but the government must avoid the temptation and pressures to support short-term projects for commercial application. Government policy must emphasize incremental, step-by-step funding in order to reduce uncertainties to the point where industry can take over the task of commercial development.

In general, most economists would accept the general principles that government should support industrial innovation when private firms are inefficient in the use of technical knowledge and when there is a divergence between private and public interest. (Pavitt and Walker, 1974, p. 12.) However, as George Eads has argued, application of these principles can lead to great abuse. They can become the rationale for completely inappropriate and extremely costly government initiatives in the area of commercial development. (Eads, April 1974.) They become the basis for government subsidization of inefficient firms and ambitious projects of dubious economic merit.

Dubious Arguments for Government Support of Technological Developments

On the other hand, this writer questions the validity of a number of reasons frequently alleged to justify government support of R and D. In particular, it is argued that there are a number of alleged reasons for government support of R and D which this author believes to be highly questionable. In particular, government funding of commercial developments is said to be necessary for the following reasons:

(1) *The Scale Argument*

Undoubtedly the most important and pernicious argument for government financing of development projects is that certain modern technologies are so expensive to develop that the commercial capital market cannot mobilize sufficient funds. (Pavitt, p. 19.) Usually such projects are justified on the grounds they will revolutionize the state of the technical art. Thus, the advocates of government funding of the supersonic transport (SST) argued that the development of the aircraft would revolutionize aircraft design and would have beneficial spillovers throughout the economy.

The arguments against the "scale argument" have been excellently summarized as follows:

> First, the commercial system in industrialized countries is normally quite capable of mobilising very large sums of money for civilian commercial developments: witness, for example, the IBM 360 series, the Boeing 747, the investments of the chemical companies in new products and large-scale processes, and of the oil companies in under-sea oil exploration and extraction. Second, if commercial money is not forthcoming for full-scale development, it is usually because entrepreneurs do not think that the technology, the market, and/or the management is such that an adequate rate of profit will be made. Third, government money invested in commercial development projects will therefore either be a substitute for industrial money, or invested in second-best projects, given that governments are not in a position to make better guesses than industrial firms about future technical and commercial prospects. Fourth, once governments invest in second-best commercial development projects, it becomes difficult to stop them, because of public commitments and of political lobbies and pressure groups. Fifth, this will lead to good money being thrown after bad, and to a degradation of the public service, which then becomes an advocate of commercially questionable projects. Sixth, it will also lead to the degradation of the commercial capacity of private firms involved in such projects which devote their resources and their skills to political lobbying instead of to production and marketing. Seventh, the arguments that a low commercial rate of return is compensated by "externalities" such as exports and the general upgrading of industrial technique (which are generally invoked in the later stages of projects as they come under mounting criticism) are spurious; there is no reason to believe that industry-financed commercial developments produce such "externalities" to a lesser degree. (Pavitt, 1974, p. 20).

(2) *Security of Supply*

A second dubious justification for government financing of commercial development both in this country and abroad is that certain high technologies are of strategic importance. For industrial or military reasons, the United States should not be dependent upon a foreign source, or should not fall behind technologically. In the past, these arguments have been applied most forcefully to aerospace, electronics, and atomic energy. With the advent of the energy crisis and the launching of Project Independence, the security of supply argument has been applied to a broad spectrum of energy development: atomic energy, coal gasification, solar energy, etc. The security of supply arguments were also used for the justification of government financing of the commercial development of both the SST and the breeder reactor.

The economic criticism of the scale argument is less applicable to the security of supply argument. It may very well be that for political or military reasons, there is justification to invest funds in a project which cannot be justified by commercial standards. But as in the case of the SST, one must be wary of this argument. Many sins are committed in the name of "national security." At the least, each such project must be examined with great care. But beyond this case-by-case approach, the experience of the past several decades suggests great caution should be exercised in financing costly development for security of supply reasons. More importantly, frequently, lower cost alternatives are available.

In this country and abroad the security of supply argument as applied to costly high technologies has led to incredible waste of scarce R and D resources. In the three Western economies where it has had most influence—the United States, Great Britain, and France—it has had deleterious consequences for the overall health of industrial technology. The history of the past thirty years is strewn with costly high-priority, low-payoff projects justified by security or prestige reasons: Concorde; Apollo; European satellite and launch projects; UK, Swedish, and French atomic projects; and a host of, computer, aerospace, and electronic projects.[14] Only the Japanese, West Germans, and the smaller advanced industrial countries have had the good sense to refrain from such temptations.

The recent history of ill-fated and extremely costly development projects undertaken for reasons of assuring supply suggests that several alternatives be considered. At the least such projects should be carried out on an incremental and step-by-step basis. The psychology of the "crash program" involving long-term and irreversible commitments should be avoided. It is extremely risky, as the British and French have discovered in their joint Concorde project, to make firm long-term commitments too early when technical, commercial, and political uncertainties are extremely high. It is best to wait until research and time have reduced the level of uncertainty before making a commitment to commercial development. The same caution may apply to many of the projects presently being considered in the United States today in the area of energy.

A second alternative is to borrow a leaf from the book of military R and D. This is the concept of basic capabilities research. The Department of Defense and many corporations support a very broad range of applied research and exploratory development in order to have the basic technology "on the shelf." The technology is there if it is required for full-scale development and production. Only sporadically has the United States outside the military area followed this concept of "on the shelf" capabilities. This policy was followed by the Atomic Energy Commission in its reactor demonstra-

[14] For the case of France, see my book, *France in the Age of the Scientific State* (Princeton, N.J.: Princeton University Press, 1968).

tion program. But on at least two occasions the United States has found itself dangerously deficient in basic capabilities. The first was after the launching of the Soviet Sputnik when the United States discovered it lacked the applied mathematics, heat-resistant materials, and propulsion technology to launch its own space program. The other occasion is the present situation with respect to energy.

Over the past several decades we have basked in the euphoria of low cost energy supplies from overseas. As a consequence, there was little incentive to develop basic capabilities in new forms of energy production, storage, and conservation. We now find ourselves hobbled because we have failed to do the necessary applied research and exploratory development in a number of critical areas: coal gasification technology; energy storage and conversion systems; and unconventional methods for energy production. The tragedy is that the development of these capabilities would not have been costly relative to the expensive and questionable Apollo project.

As we move into a highly uncertain future, the likelihood of other surprises comparable to Sputnik or the energy crisis is fairly great. Domestic or foreign events may necessitate the development of new technological capabilities. To be prepared, the United States must undertake basic capabilities R and D across a broad spectrum of science and technology. While this type of research is fortunately relatively cheap, such a program of "on the shelf" technology does necessitate the development of institutional mechanisms which can identify and support scientific and technological areas where America's basic capabilities and "on the shelf" technology are judged to be deficient.

The Case of Energy R and D

It would be foolhardy indeed to suggest in this report the direction in which the medium-term or long-term solution to the energy crisis lies: fission energy, off-shore oil, shale oil, fusion energy, solar power, coal gasification, etc. Very few experts are in agreement and confusion reigns. But it is precisely this extremely high level of uncertainty which should be our guide in the formulation of a policy, or perhaps more appropriately, a strategy by which to solve our long-term energy needs and the dangers of over-reliance upon politically vulnerable foreign sources of petroleum. By substituting "strategy" for "policy," I mean to suggest that what is important is the way we go about setting and achieving our objectives with respect to energy rather than the policy objectives or policies themselves. As I have emphasized throughout this report, the great technical and market uncertainties which surround technological innovation necessitate an incremental, step-by-step approach. There is a need continually to revise objectives and policies in the light of the advance of scientific technical, and market factors.

Much of the confusion with respect to energy is due to the fact that we appear to be seeking two contradictory goals. On the one hand, through conservation and the development of alternative sources of energy, the United States has sought to improve its bargaining position in order to force down the price of OPEC oil. On the other hand, the objective of Project Independence is to decrease our dependence upon foreign sources of petroleum. In so far as we achieve the first objective, of course, we decrease the incentive of the private sector to invest billions in high cost alternative sources of energy in order to achieve the latter. The proposed resolution of this dilemma is the concept of a negotiated floor price for oil which would be a market clearing price for domestic alternatives to OPEC oil (about $7–8 a barrel).

While accepting the need to decrease the dependence of the United States on politically vulnerable foreign sources of energy, one can nonetheless challenge the political feasibility and question the cost of Project Independence and the related concept of a negotiated floor price for oil. If security of supply and a reduction of vulnerability to another oil embargo constitute our goal, there are undoubtedly less costly alternatives to that of building an unnecessarily high price for energy into our economy. Alternatives include the opening up of the Naval reserves on a standby basis or Arthur Okun's proposal for government purchase guarantees for high cost U.S. energy products in the event OPEC dramatically lowered the world price of oil. But this is a subject outside the concern of this report. What is of concern to this report, however, is the policy which has been adopted with respect to the innovation of new energy producing technologies.

In its desire for a "quick fix" of the energy problem, the United States has adopted the highly questionable approach to technological innovation identified with the ill-fated Technology Opportunities Program. Recalling the success of the Manhattan District Project for the development of the atomic bomb and Project Apollo to land a man on the moon, the government is applying the "crash program" philosophy to the development of new sources of energy. The government has assumed the role of entrepreneur in the development of commercial products for the civilian economy.

As this report has emphasized, this is a task which governments do poorly. In contrast to military or space projects, considerations of cost and market demand are central. For this reason, decisions with respect to the commercial development of technology should be left up to the private sector. But beyond this general reservation about the government's role in commercial innovation, the technical and market uncertainties in the area of energy development remain extremely high. The reduction of these many uncertainties rather than the initiation of "crash programs" to develop this or that technology should be the primary emphasis of our R and D effort in energy and the long-term solution to our energy needs. Lastly, given the strong reservations of so many experts including those in the Federal Energy Administration itself concerning the feasibility of any major technological breakthroughs or other developments in the next decade and a half which would significantly reduce our growing dependence upon foreign oil, the better strategy would be to reduce technical uncertainties across a broad front of technology rather than the premature overemphasis on one or two particular technological developments.[15]

For these reasons, one can at least raise serious questions with respect to the newly created Energy Research and Development

[15] On energy R and D, See, Federal Energy Administration, *Project Independence Report*, November 1974, chapter nine. For a detailed critique of Project Independence, see, Victor McElheny, "Experts Skeptical on Ford's Energy Plan," *The New York Times*, March 1, 1974, p. 1.

Administration's (ERDA's) heavy emphasis on the breeder reactor, in particular the liquid-metal fast breeder reactor (LMFBR). Since at least 1967, the LMFBR has been given a high priority by the Atomic Energy Commission as the solution to our long-term energy requirements. As we have already seen, this emphasis on the breeder reactor was further accentuated by the Technology Opportunities Program. And, currently, although ERDA will increase funding of non-nuclear research, highest priority is still given to the breeder reactor.

In contrast to the incrementalism and step-by-step reduction of uncertainties advocated by most experts on technological innovation, the United States has adopted just the opposite approach to the breeder reactor. It has followed the "crash program" approach of the military services which invariably is based on overly optimistic forecasts of success and leads to excessive waste. Since 1972, the estimated cost of the total breeder program has increased from $1.8 billion to more than $10.7 billion, and the end is not yet is sight.[16]

In emphasizing the breeder reactor, the government under-emphasized research and development on other technologies whose development would have lessened our present dilemma and perplexing situation. Most notable perhaps was our neglect of research on coal technologies: Coal gasification, the manufacture of fertilizers from coal, the removal of sulphur from coal stack gas, etc. Despite our incredible reserves of coal, the methods for its recovery, combustion, and conversion remain primitive. Similarly, too little was done to advance fusion and solar energy or to develop energy storage technologies. How different our present situation would have been if we had developed "on the shelf" technologies in coal and other areas. One can only wonder whether our continuing fascination with the breeder will cause the shelf to be too bare to meet the challenges we may face 10 to 20 years from now.

In addition to its environmental dangers and its consequences for nuclear weapons proliferation, a number of experts challenge the LMFBR on grounds of cost. As in the case of other government-initiated, big technology projects (Concorde, for example), the LMFBR was initially selected for commercial development because it appeared to be technically feasible and would contribute to national leadership in an important area of technology. Now with its accelerating costs, the rationale for the breeder over other types of reactors and projects in other areas of energy production has become that it will decrease our dependence upon foreign sources of energy.

This report obviously cannot evaluate the technical and economic arguments for and against the breeder. But it does challenge the approach it represents with respect to the role of the government in the commercial development of innovation and to the long-term solution of developing alternative sources of energy production, conservation, and utilization. Unless an overwhelming case can be made for government intervention, commercial decisions should be left up to the private sector with its emphasis upon market factors. While the government can perform a critically important function in shaping the market and market conditions, the appropriate role for the government in energy as in other areas of technology is the

[16] *National Journal Reports*, Vol. 7, No. 9, March 1, 1975, p. 305; *The Wall Street Journal*, May 6, 1975, p. 23.

support of research and experimental development in the interest of reducing technical uncertainties.

A second major question facing ERDA is whether it will tend toward the AEC or the NASA approach to science and technology. The AEC has tended to emphasize basic science at the expense of engineering; furthermore, it has tended to neglect the education and development of the next generation of engineers and technologists. NASA, on the other hand, has emphasized engineering and assumed the responsibility for the support of engineering education. The pressing need for energy research and engineers makes it very important that ERDA follow in the footsteps of NASA. Unfortunately, the fact that ERDA has incorporated so much of the former AEC suggests that it may follow the AEC approach to basic science, engineering research, and engineering education. If so, it would have unfortunate long term implications for our national capabilities with respect to its energy-related technologies.

Given the incredible technical and market uncertainties surrounding energy today, the present government program of energy research and development should heed the warning of Nelson and colleagues (1974, p. 173):

> Under such circumstances the most fruitful way to proceed is sequentially and experimentally; neither doing nothing because knowledge is less than perfect nor leaping farther than necessary in a prejudged direction. Government policy making presently has a tendency to vacillate between these extremes. There is a tendendy to delay for a long time the introduction of a new program because of uncertainties, and then suddenly to jump in fully with a large commitment to a prescribed program, with no better knowledge base than before, when political pressures for doing something become strong. Once proposed or initiated, the program is then popularized among the public and in the Congress as a sure antidote, rather than as a promising probe of the environment.

From this perspective, the emphasis of our energy research and development effort should be to support R and D across a broad spectrum of energy-related technologies and leave it up to the private sector to bring promising technologies to commercial development. The selection of R and D projects for emphasis should be on an incremental and step-by-step basis. But beyond this supporting role, through its regulatory, taxation, and purchasing policies the government can establish the framework of decision and the direction in which the private sector should move such as decreased dependence upon fossil fuels, the movement toward an electric or hydrogen-based economy, the achievement of greater energy self-sufficiency, etc. It is this role of the government in establishing overall national priorities, i.e., a strategy of technological innovation that this report seeks to stress. From this perspective we can learn much from the successes and failures of other societies, the subject to which we shall now turn.

VI. THE RELEVANCE OF FOREIGN EXPERIENCE

In the contemporary world there are two societies which provide models of what to do and, perhaps of greater importance, what not to do with respect to technological innovation. On the one hand, the Japanese have pursued an exceptionally successful policy for technological development since the end of the Second World War. While the Japanese economic and political structure differs significantly from that of the United States, the Japanese experience still has relevance for the United States. On the other hand, the British have made many serious mistakes in the area of technological innovation over the past several decades. Unfortunately, American policies have been closer to the British than to the Japanese model. In this brief analysis, we will focus only upon those aspects which are relevant for our present concerns.

Although the experiences of other societies in the area of government support for technological innovation have limited utility for the United States, they do suggest pitfalls to be avoided and policies that have worked with great success. The lessons to be derived from a quick look at British and Japanese experience, for example, are especially important for two reasons. In the first place, pressures are presently developing rather rapidly in the United States to pursue courses of action which have been serious failures abroad. Secondly, the United States situation with respect to technology is now such that policies which have worked very well in particular countries have an increased relevance for the United States.

JAPAN'S TECHNOLOGICAL STRATEGY [17]

Japan's technological strategy has been characterized as one that exploits a variety of "technological niches." Under the heavy-handed guidance of the Ministry of International Trade and Industry (MITI) and with careful analyses of potential export markets, the Japanese have purchased from abroad the technologies through which they have achieved their impressive rate of economic growth and export trade. To achieve their economic conquests, they have, in effect, employed the same techniques of close government-industrial cooperation, individual discipline, and unswerving dedication to the objective that once enabled their military conquests.

The Japanese have been able to concentrate their energies and resources on commercial technological development because of several highly favorable circumstances. (Brzezinski, 1972.) In the first place, their alliance with the United States has relieved them of heavy expenditures on defense. A remarkably small fraction of their

[17] The literature on the Japanese miracle is rather extensive, but several studies are especially relevant: M.E. Dimock, *The Japanese Technocracy* (Walker, New York, 1968); R. Guillain, *Japan Troisième Grand* (Editions du Seuil, Paris, 1969); H. Brochier, *Le Miracle Economique Japonais* (Calmann-Levy, Paris, 1965); OECD, *Reviews of National Science Policy-Japan*, (Paris, 1967); Terutomo Ozawa, *Japan's Technological Challenge to the West 1950–1970, Motivation and Accomplishment* (MIT Press, 1974); and Merton Peck, "Infusion of Technology and the Mysteries of the Catch-Up" (mimeo) undated.

total R and D has been defense-related (Table 40). And, secondly, the United States has encouraged the diffusion of American advanced technology to Japan. Yet, the important fact is that the Japanese took advantage of this situation to do most of the right things.

In the first place, the Ministry of International Trade and Industry in conjunction with the banking system and the large trading houses has provided central guidance and leadership to the Japanese economic revival. At the highest levels of government, industry, and banking the Japanese have coupled and integrated economic and technological policies. Appropriately labeled, but frequently misunderstood, "Japan Incorporated" gave central direction to the implementation of Japan's policy decision to rebuild the Japanese economy upon the most advanced technologies and industries.[18]

The second most noteworthy feature of the Japanese experience is that they have successfully coupled economic and technological policies to achieve one overriding objective: rapid economic growth. Through various economic policy instruments the Japanese government and particularly MITI created incentives and disincentives which forced Japanese industry to innovate and adopt progressively higher levels of technology. For example, contrary to the myth that Japan Incorporated means government protection of industrial firms, Japan's highly selective and discriminating tariff policy has been ruthless with respect to inefficient and low-technology firms. It has been geared to wipe out industries in low-technology and decreasingly competitive sectors (textiles, shoes, etc.) and to protect firms in higher technologies (electronics, automobile, etc.) until they are strong enough to meet foreign competition. Furthermore, in contrast to American industry the Japanese have tended to keep their high-technology industry at home. Japanese foreign direct investment is mainly in extractive and low-technology industries, though this is changing due to Japanese concern over trade barriers.

Thirdly, the Japanese have stressed the demand rather than the supply side of technological innovation. Market demand and profitability have determined the allocation of R and D resources. As such, and again contrary to myth, the Japanese government has played almost no direct role in technological innovation. In contrast to the United States most of the funds for R and D are provided by industry itself. The major contribution of the government has come through a heavy investment in education and the provision to industry of a highly skilled labor force, including scientists and engineers. In addition, the government has financed applied research and experimental development in areas of commercial importance (shipbuilding, for example). The commercial development of technology has been left up to industry and its assessment of user demand. The Japanese government through its overall economic policies has managed demand and the economic environment, but it has left to private industry the task of bringing a technology to the stage of commercial development.

In contrast to the United States, the Japanese have emphasized the adoption of foreign technologies and applied R and D in consumer technologies. They have given relatively little attention either to basic

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[18] For an intelligent and balanced analysis of "Japan Incorporated," see U.S. Department of Commerce, *Japan—the Government-Business Relationship*, February 1972.

research or to big, prestige technologies. The greatest gains to Japanese economic growth and productivity have come, in fact, through the enhancement of intermediate products (materials, supplies, etc.). The Japanese success in importing and adapting technology has been due to the development of a strong R and D capacity within Japanese industry. Through the employment of large numbers of scientists and engineers, Japanese industry has been able to monitor, select, and adapt foreign technologies. In general, these professionals' have performed adaptive rather than original research.

Among students of Japanese economic and technology policies a debate has taken place over the past several years regarding the feasibility of the Japanese formula in the future. Certainly two of its fundamental ingredients are changing. In the future, the Japanese will have to invest more of their economic and technical resources in defense. Additionally, as their economy has come abreast of the American economy and as American firms become more restrictive about licensing their technology to the Japanese, Japan will be less able to depend on importing foreign technology. For these reasons, one will undoubtedly see a greater Japanese emphasis on basic science and technological innovation. The issue which only the future can decide is how well the Japanese can make this jump from successful adoption to technological innovation.

The British Technological Strategy [19]

It is undoubtedly a misnomer to speak of a British technological strategy. Unlike the Japanese, British economic and technologies policy has had little clear direction. Cooperation among the government, financial, and industrial communities has been poor. Many policy and institutional initiatives have been tried, failed, and eventually abandoned. Economic and technology policies have frequently been at cross purposes rather than reinforcing one another. On the one hand, the British have sought to rebuild an industrial and economic structure which had been tied to an imperial system. On the other hand, British economic policy has emphaszied redistribution of wealth and the nationalization of industry at the same time that they have recognized the need to create large, efficient industrial entities to compete against the Americans, Germans, and Japanese.

Underlying the British malaise has been the problem of making the adjustment from the status of a global imperial power to that of a middle-sized European state. The emphasis and errors of British technological policies can be attributed in large measure to the economic and psychological difficulties of making this adjustment. While this unique circumstance would seemingly make the British experience irrelevant to the United States, the contrary is the case. As we emphasized in the first section of this report, the United States today faces in part (though fortunately to a much lesser degree) the problem which has long faced the British. The relative industrial decline of the United States poses a similar challenge to us. Moreover, in our effort to meet this challenge we face the same temptations to make the same errors which the British have committed.

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[19] In this section I have relied heavily on several sources: Pavitt, 1974; various OECD publications; and Freeman, 1974.

The experience of Great Britain in technological innovation presents a curious paradox. At the same time that many of the most important and remarkable technological innovations of the past several decades have British origins—jet propulsion, holography, hovercraft, radar, etc.—the British have failed to take full advantage of these innovations and on the whole have made very poor use of their rich scientific and technological resources. The overall failure of British technological policy has been a continuing source of frustration for successive British governments. Despite the fact that government policy in Great Britain has been to make goverment financed R and D more relevant to industry, the British have failed to meet this objective.

The reasons for these failures obviously lie deep in British society and economic organization. Yet, several aspects of British policy for the support of technology appear especially important. Moreover, British experience holds noteworthy lessons for the United States because of increasing pressures in this society to move precisely in the direction which has proven so unfortunate for the British. As in Great Britain, there are calls in the United States for disguised subsidization of industry under the subterfuge of security of supply, the scale of technology, and so forth.

In the first place, British Government expenditures like those of the U.S. have been overly concentrated in a relatively few high technology areas such as defense, space, and atomic energy, (Tables 4 and 5). The government has taken upon itself the role of entrepreneurship and has concentrated upon commercial development instead of on research, exploratory development, and related activities. In substituting its judgment for that of private enterpreneurs with respect to the commercial "ripeness" of particular high technology projects, the government has assumed a responsibility and tasks which governments do not do well. As a consequence of this neglect of the market very few of these costly projects have had commercial success. (Pavitt, 1974.)

Secondly, and directly related to the first weakness, the British Government in a number of significant cases has made commitments to full-scale commercial development of particular technologies too early and on too big scale. The British Government has failed to adopt the wiser policy of an incremental, step-by-step approach to R and D policy. At the same time, too little has been spent on the necessary applied research, project planning, and exploratory development which should precede the commitment to large scale development. As a consequence, there has been a neglect of more traditional sectors of the economy which for historical and institutional reasons tend to under-invest in R and D.

And, thirdly, the British have failed to integrate sufficiently the three estates of science and technology: universities, government, and industry. They have failed to create the necessary mechanisms to bring together the sources of new scientific-technical knowledge and the industrial utilizers of knowledge. A disproportionately high fraction of British R and D has been conducted in government laboratories or in industry-wide cooperative laboratories catering to specific industrial sectors (steel-making, machinery, textiles). While this latter set-up has served to improve the state of the several technical arts, as the so-called Rothchild Report points out, the spill-over of government-supported military, and related research into the private industrial sector has been minimized.[20]

In a sense, the underlying failure of British policy for R and D has been that the government has tiied to *supplement* rather than *complement* the private market. (Pavitt, 1974, p. IV.) Unlike the Japanese they have failed to couple economic and technology policies. As a consequence, although the British are among the most technologically rich and resourceful people in the world, they have been unable to harness these resources to generate a sufficiently high rate of economic growth and competitive exports.

The British experience illustrates one last point which should be underscored. While the extent of government support of civilian, industry-related R and D varies in industrial economies, it is curious to note that the level of government support for commercial development is inversely correlated with the technological prowess of the economy. In addition to Great Britain, the two industrial economies with a relatively high level of government support—France, and the Soviet Union—tend to trail those economies where the government's role in big technology has been least: Japan, Sweden, The Netherlands, Switzerland, and the Federal Republic of Germany. Although one cannot draw the conclusion that government support of big technology is harmful to R and D, this negative relationship at least suggests that government support in itself is not the solution to a declining tech noligical base.

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[20] U.K. Government, *A Framework for Government Research and Development*, HMSO (Cmnd. 4814).

VII. CONCLUSIONS

The overall recommendation of this report is that technology policy must be coupled with socio-economic policy. At all levels of policy-making 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.

As we have argued, among modern societies the Japanese (and perhaps the Germans) have been most successful in creating the institutional structure and national policies to integrate technology and economic policies in order to achieve their professed goal of rapid economic growth. In the case of the United States and Great Britain, although both societies have the richest scientific and technical resources in the non-communist world, they have both been much less successful in integrating technology policy into the larger framework of socio-economic policy and national goals whether those goals be a more rapid rate of economic growth, more competitive exports, or a cleaner-safer environment. It is, therefore, imperative that we improve our ability to couple technology and our goals. Although technology alone cannot solve our problems, it is today a central ingredient in economic growth, competitive exports, and the solution of domestic problems.

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, some one 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 coupling of technology and user needs requires that government programs be problem-oriented. The need is to think, in terms of problems (user needs or demands) which require solving and to ask how technology could help solve the problem. What are the technological roadblocks, if any, to solving recognized economic and social problems, and what can the government do to remove those roadblocks? It may very well be that the roadblocks are economic, legal, or social, but technological roadblocks may be identifiable. For example, what are the technological roadblocks to the development of such socially recognized needs as a less-polluting automobile engine, better construction methods, and energy-storage?

The emphasis on problem-solving, user need, and demand-pull should carry over into all aspects of government policy-making. In particular, the following question must be asked: How do government policies and regulations influence the direction and character of technological innovation and productivity in the private sector? Or, to put it another way, how could government regulatory, taxation, and other policies be used in order to influence technological innovation in a socially desirable direction? As government economic and related policies are among the most important determinants of civilian technological innovation and industrial productivity, how these policies affect the behavior and efficiency of industrial firms should be a major concern of government policy.

Unfortunately, we do not know very much about the net impact of government policies and regulations on specific industrial sectors. Moreover, purchasing, regulatory, and related policies affecting an industrial sector are frequently made by different agencies with little concern given to the overall effect on innovation and productivity. Nor does any agency seek to take a more olympian view of the overall impact of government policies on the innovative behavior of industry.

In response to this situation, Eads has proposed a research-impact statement whenever a government agency undertakes a major action. (Eads, March 1973, p. 7.) Thus, the Interstate Commerce Commission should consider the impact of its rate structure on the railroad industry's incentives to innovate. The same type of evaluation should be required of the Food and Drug Administration, Environmental Protection Agency, General Services Administration, etc. At the least, Eads reasoned, these exercises would raise the "innovative consciousness" of the agencies dealing with specific industrial sectors.

The concept of consciousness-raising of government agencies with respect to the impact of their regulations, purchasing, and standard setting policies upon innovation is the central purpose of a recent and potentially significant departure in government policy toward industrial R and D: the Experimental Technology Incentives Program (ETIP). Through its program of policy and technological experiments, in cooperation with responsible government agencies, this program seeks to encourage a greater coupling of economic and technology policy. Through its emphasis on increasing the incentives to innovate and removing the roadblocks to socially desirable technological innovation, its approach is demand-pull rather than technology-push. However, rather than spell out the rationale and the specific program of ETIP, a copy of its progress report has been appended to this report.

In the judgment of this report, ETIP represents one of the best conceived and potentially most important efforts being carried out in the government today "to find ways to stimulate R and D and the application of R and D results." Its philosophy and approach are based on what is known about successful technological innovation. Unfortunately, this very modest program has been in operation a little over a year; it has, therefore, as yet few achievements to which it can point. More significantly, its location in the National Bureau of Standards provides it with too little visibility and leverage with respect to the vast government R and D program it is seeking to influence. To be effective, this type of effort could be more strategically placed in the government policy machinery in order to facilitate the coupling of technology and economic policy. We will return to the subject later in this section of the report.[21]

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 inno-

[21] An approach similar to that of ETIP has been advocated by the Science Policy Committee of the American Association for the Advancement of Science in order to encourage more R and D on the part of all government agencies. See the testimony of Jurgen Schmandt, U.S. House of Representatives, Committee on Science and Astronautics, *Federal Policy, Plans, and Organization for Science and Technology—Part II*, 93rd Cong., 2nd Session, 1974, pp. 105–21. See also Schmandt, 1974.

vation. 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 policymaking 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.

A recent and dramatic case in point is that of the catalytic converter to control automobile emissions. Instead of requiring every automobile engine to be equipped with a catalytic converter, an alternative would have been to have experimented with the converter on a sufficiently large sample of cars. Other approaches to solving the problem of automobile pollution might also have been tried on an experimental basis. Such an experimental effort to reduce the technical unknowns and uncertainties would appear in retrospect to have been the wiser course of action. When we try to change everything at once or, as in the case of the breeder reactor, commit most of our resources to one solution to a problem we run a very grave and unnecessary risk.

In the absence of secure knowledge with respect to market imperfections which cause an underinvestment in innovative activities and with respect to the optimum level of government support for R and D, the appropriate strategy as Nelson et al recommend should be to proceed sequentially and experimentally. It is far preferable to invest small amounts and test a number of policy instruments rather than make massive commitments to a few, untested projects. The government should in fact emulate the R and D strategy of the more successful innovative private firms: (1) Under conditions of high uncertainty, the primary purpose of R and D should be to resolve the key uncertainties through a pilot or experimental program; (2) these programs should be modest and should seek to alleviate the problem at the same time data are obtained with respect to the most fruitful course of action; and (3) procedures and criteria of evaluation and consequent redirection of the program should be built into the program. (Nelson et al, 1967, p. 174–75.)

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 commerical 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.

Unfortunately, the United States has erred in both respects. On the one hand, the United States government has—incorrectly, I believe—assumed the entrepreneurial role in the commercial development of the breeder reactor; it has been and is tempted to assume a similar role with respect to other costly technological innovations. On the other hand, the United States has underinvested in R and D related to civilian technological development. We have concentrated our scientific and technical resources in a relatively narrow range of "big science and technology." If we are to increase our technological options and "on the shelf" technology, the government's role in the innovation of civilian technology must be put right.

One of the major differences between American and European systems for conducting R and D is the important place in the latter of government-funded technological institutes. In contrast to Europe, and to the situation prevailing in the American agricultural sector, the United States government has not assumed the responsibility for supporting industrial research in such sectors as steel, machine tools, construction, etc. For this reason, it has been proposed that the government establish a National Institute of Technology to do for various industrial sectors what the Department of Agriculture has done for the farmer (Nelson et al, 1967).

There are three reasons why a similar pattern of institutes might make sense for the United States. In the first place, research laboratories in particular industrial sectors could carry out the type of long-range and applied research which the private sector tends to neglect. While product development and commercial innovation would be left to the private sector such government-funded laboratories could advance the "state of the art" and thereby reduce technical uncertainties. Secondly, technological institutes or a National Institute for Technology could provide consumers and the public service sector with independent and critical assessments of technological opportunities and options. By identifying and specifying user's needs and market potential, the institutes could stimulate socially useful innovations. And, thirdly, these institutes could assess and evaluate innovations from the perspective of social and economic needs, (Pavitt and Walker, 1974, p. 5).

In particular, through advancing the state of the technical art and research contracts to private firms and engineering schools such a technological institute could give encouragement to what Scherer above has identified as one of the major sources of technological innovation—the medium-sized firms. By increasing the range of technological options, a government program which financed technical research and experimental development might improve the environment for rapid technological progress. If properly carried out, this type of effort would increase the probability of the entry into the economy of new firms with radical innovations.

Yet, one can not in all honesty be very sanguine about this possibility. The experience of the United States and other countries with government-initiated programs to disseminate to private industry the results of government-sponsored research does not hold out much promise with respect to their effectiveness. One of the most ambitious has been that of NASA which established regional dissemination centers and other transfer mechanisms to funnel the results of NASA research and development programs into the private sector. In the opinion of one study of this program, the results have been rather meager (Doctors, 1971).

The problem with this type of approach to innovation is that it tends to decouple technology from user needs. It takes the technology-push rather than the demand-pull approach to technological innovation. Nonetheless, it is undoubtedly worth considering in those areas such as construction or machine tools where the structure of the industry precludes a major program of R and D. However, the innovation of such programs should be undertaken only if studies of particular industrial sectors show specific needs and should be undertaken on an experimental basis. And, lastly, the appropriate model to follow is that of the former National Advisory Committee on Aeronautics which financed background fundamental research, experimental development, and demonstration projects.

The Question of Institutional Mechanisms

As many students of American government have observed, when Americans recognize a problem or a need their first response is to create a new organization to solve it. This has certainly been the case in response to our recognized technological problems. There are at least half a dozen proposals for the establishment of a council of scientific and technical advisors to the President.[22] Vice President Rockefeller has been assigned the task of making a recommendation in this area.

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 achievement of these objectives does not necessarily mean a major institutional change. The American system would not tolerate a MITI which has so successfully coupled economic and technology policies in Japan. But we can do far better than we do at present. A step in the right direction would be taken, for example, by infusing into all levels of government the concept of coupling economy and technology policy which underlies the Experimental Technology Incentives Program. This Program itself might be given a better

[22] See, for example, National Academy of Sciences, *Science and Technology in Presidential Policy-Making—A Proposal*, Washington, D.C., June 1974; U.S. House of Representatives, Committee on Science and Astronautics, *Federal Policy, Plans, and Organization for Science and Technology—Interim Report*, 93d Cong., 2d Sess, 1974.

strategic location in the Executive Branch where it could encourage a more experimental and problem-oriented approach to policy-making and technological innovation on the part of government agencies. It could thereby more effectively undertake initiatives leading to the development by government agencies of purchasing, regulatory and other policies which in turn encourage more socially and economically beneficial technological innovation. On the congressional side, a similar role could be performed by the newly created Congressional Budget Office.[23]

In seeking a home for the types of analyses and studies presently being carried out by the Experimental Technology Incentives Program (ETIP) one is brought face-to-face with an extremely important lacuna of government policy-making. The problems of R and D are those of micro-economic policy, that is, of that aspect of economics which deals with the determinants of prices and outputs of individual goods and services. In effect, what economic policies should be pursued in order to obtain a particular good (technological innovation) and service (scientific knowledge)? Yet, there is no government agency which has the primary responsibility for overseeing the micro-economic policies of the government, such as they are. For example, although the Council of Economic Advisers does devote some attention to micro-economic policy, its responsibility is primarily that of macro-policy, i.e., the general state of the economy. While one might expect regulatory agencies to be concerned with the micro-economic policy aspects of the specific sectors they regulate, that is, concern over the effects of regulatory policies on the output of goods and services, this too is seldom the case. In short, at both the highest policy level and at the operational level, the government lacks an adequate micro-economic analysis capability.

For this reason, the central argument of this report that economic and technology policies must be coupled and integrated confronts the fact that micro-economic policy hardly exists. The fundamental need therefore is for the federal government to develop a greater capability for micro-economic policy. In contrast to the present situation there must be a greater government focus on micro-economic aspects of the American economy. From this perspective, R and D is but one of several "goods or services" whose output must become the concern of a greater government emphasis on micro-economic policy and its impact on the private sector.

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.

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[23] The appointment of Alice Rivlin to direct the staff is a hopeful sign. Her experimental approach to policy-making as set forth in her book, *Systematic Thinking for Social Action*, (The Brookings Institution, 1971) parallels the one advanced in this report.

In theory, the Office of Management and Budget could provide the leadership with respect to micro-economic policy. However, as its relationship to other agencies is frequently an adversary one, its utility in encouraging micro-economic studies at the agency level is undoubtedly limited. The Council of Economic Advisors or the Domestic Council are other possibilities. Or a Productivity Council with responsibility for sponsoring micro-economic studies might be created. Yet another possibility is that the responsibility for micro-economic policy analysis and for policy execution could be divided. There could be a productivity or some such council in the Executive Office which is responsible for policy execution. In addition, it could be supported by an office of micro-economic analysis located elsewhere in the executive branch. Such has been the situation, for example, in the area of telecommunications where the Office of Telecommunications in the Department of Commerce carries out relevant policy studies and the Office of Telecommunications Policy in the Executive Office of the President has responsibility for policy implementation.

The important point, however, is not whether this or that reorganization of administrative responsibility is to be preferred. It is rather that micro-economic analysis in general and the coupling of technology and economic policies in particular should be given a much higher priority by the federal government. This could be achieved if the highest levels of the Executive branch recognized this need and encouraged the type of approach to problem-solving being carried out by ETIP. What is important is the attitude that the government takes with respect to technological innovation and its important role in solving our social and economic problems.

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 individualists 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 light of our pressing national problems the United States must develop an overall national strategy for science and technology.

We must develop the necessary mechanism by which to determine national priorities for R and D and the means by which to achieve them. The details need not be specified here. Such a mechanism for establishing and implementing a national strategy for science and technology could, as some have proposed, parallel in structure the Council of Economic Advisors. Or, it could be a revival of the President's Science Advisor and Office of Science and Technology. But what is of critical importance is that its functioning take into account what we have learned from past experience and empirical studies about the scientific and technological enterprise.

The foremost lessons we have learned, or at least should have learned, are the following: (1) One of the primary characteristics of the scientific and technological enterprise is the factor of *uncertainty*. The state of scientific knowledge and the technical art are in constant flux and it changes at a constantly accelerating pace. (2) Successful innovation involves the coupling of technical knowledge and the nature of the market. Both in turn involve high degrees of uncertainty and the successful marriage of the two is exceptionally difficult to achieve; (3) The comparative advantage of the government lies in the funding of basic and applied research as well as experimental development. The government's record as entrepreneur or marriage broker between technology and the market is not a very good one. From these considerations flow the basic requirements for formulating and implementing a national strategy for science and technology.

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.[24] 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

[24] 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.

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 danger 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 supercede 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 underinvest 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 in this direction of subsidizing and protecting inefficient industry we would be following the British rather than the Japanese example. Invoking a variety of rationalizations 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.

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APPENDIX

Incentives for Technological Change

A Progress Report

Experimental Technology Incentives Program

March 26, 1975

"To find ways to stimulate desirable technological change so as to improve productivity in Government and industry."

Highlights

Since ETIP became operational a little over one year ago, the following measures of progress have been obtained:

(1) The Federal Power Commission is taking an active role in helping State public utility commissions (over which the FPC has no authority) solve key investment problems of electric utilities.

(2) The use of life cycle costing (LCC) has been introduced at GSA and is becoming widespread.

(3) In purchases of 27,000 room air conditioners and 8,000 hot water heaters using LCC, average energy efficiency increases of 21% and 11%, respectively were obtained, over what would have been obtained using the traditional lowest-purchase-price method. In the case of the hot water heaters, technology was introduced that had not previously been used in the U.S.

(4) In a dramatic break with tradition, the Veteran's Administration is actively seeking to use its purchasing power to stimulate the development of more cost-effective health care products and systems.

(5) A procedure being tested in cooperation with the Nuclear Regulatory Commission for accelerating the development of standards to facilitate the design, construction, and licensing of nuclear power reactors appears to have already proven dramatically effective.

(6) GSA has committed $200 million of its purchasing pwer to ETIP experiments, and the Federal Supply Service has created an Experimental Technology Office to manage ETIP experiments and to incorporate the lessons of those experiments into GSA policies.

(7) The Small Business Administration has created a Technology Applications Office for the same purpose.

(8) The use of Value Incentives Clauses has been introduced at the Federal Supply Service and incorporated in *all* FSS purchase contracts exceeding $100,000.

(9) For the first time in memory, the EPA is actively seeking to incorporate incentives for R&D in its regulatory planning.

I. Background

A. Program History

During the late 1960's and early 1970's technology became recognized as an important economic resource: As the largest component of U.S. productivity growth, it is a major contributor to price and cost stability; and technology-intensive products and agriculture (which in the U.S. is highly dependent on technology) are the only U.S. export categories with a favorable foreign trade balance. They thus help pay for petroleum and other mineral and low-technology imports.

With this as background, a debate arose in the Executive Offices as to the proper role of the Federal Government in the promotion of civilian technology. It was clear, for example, that the Government does not control the production of civilian (as opposed e.g. to defense) goods, and that the relationship between Government actions and civilian technological change were complex and not well understood.

In this context ETIP was created at NBS by Presidential mandate in early 1972 "to find ways to stimulate R&D and the application of R&D results."

Due to various administrative and operational delays, a full-time program director was not on board until September 1973, and operating funds were only released for program use in February 1974. ETIP is thus little more than one year underway.

B. Program Philosophy

Private sector investment in technological change is by nature a risk investment. Often the risk and the cost are greater than necessary due to government action or inaction. Government R&D programs reduce some of the risks and costs. But it is widely recognized that most of the costs (and much of the risk) associated with civilian technological change lie outside the realm of R&D. This includes factors such as new tooling and inventories; the marketplace; federal, state, and local rules and regulations; taxation; foreign trade policies; and labor quality and practices.

In the past the Federal Government has had explicit technology policies only when it was promoting through R&D sponsorship a few specific technologies such as nuclear power or mass transit, or when it has sought to constrain the adverse effects of technology through environmental or safety regulations and the like.

Virtually everything the Government does, however, influences or can influence the environment for technological change. A few examples suffice:

While serving to protect the public from undue economic or physical harm, regulatory agencies frequently impose unnecessary costs, risks, delays, and constraints on technological change. The estimated unnecessary costs alone amount to billions per year.

The Government is the largest purchaser of most civilian goods produced in the Nation. Traditionally, Government practices have emphasized lowest purchase price, which in turn has meant older technology. But Government purchasing could lead the market, thereby reducing market entry risks for new products while simultaneously obtaining greater value for the taxpayers' dollar.

Unlike their defense and space counterparts, agencies that sponsor applied civilian R&D do not control the production of nor do they purchase the goods flowing from this R&D. Yet these agencies typically give little thought to the use of their R&D results before and during the conduct of the R&D. As a consequence the application of this R&D, which amounts to some $5 billion per year, is widely recognized as being very poor.

Small technology-based businesses, which have been key contributors of important innovations, find it increasingly difficult to raise venture and equity capital. They also face regulatory compliance costs that are proportionately greater than for larger firms.

C. Purpose

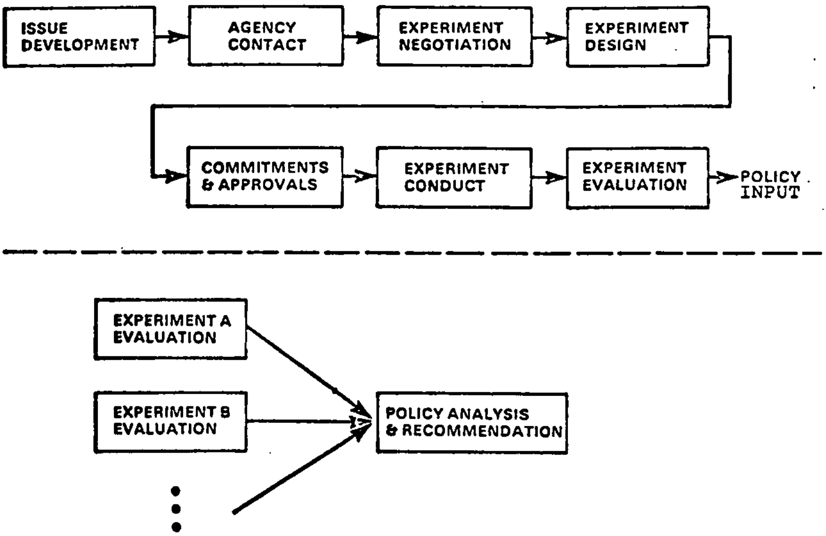
ETIP's objective is to find ways to stimulate desirable technological change so as to improve productivity in Government and industry.

D. Program Strategies

In this context, and intending to have the greatest possible impact on Government policies and practices, ETIP has selected as its basic operating strategy the design and conduct of policy experiments in close cooperation with those agencies whose responsibilities and activities are relevant to ETIP's goals. Specifically, ETIP helps these agencies design policy experiments, and when appropriate it provides funds to cover the extraordinary costs associated it with conducting experiments. In return, ETIP asks that its agency partners make a serious high-level commitment to the conduct of the experiments, and contribute their own resources and staff. The flow chart in Exhibit One displays this process.

EXHIBIT 1

ETIP POLICY DEVELOPMENT PROCESS



The advantages of working in this manner are threefold:

(1) Actual experience with policy change is obtained, which is intrinsically better than speculation about hypotehtical change.

(2)Those who would implement subsequent formal policy change (i.e., the agency staff) are gaining a firsthand understanding of the change, which should materially facilitate the transition.

(3) If an experimental change proves worthwhile, the job of convincing those who need to approve a formal change is facilitated.

II. Program Area Activities

A. Procurement

ETIP's procurement interests focus on three activity categories:

(1) Finished goods for Federal Agencies.

(2) Finished goods for State and local agencies.

(3) Federal work space (buildings).

In pursuing its procurement interests, ETIP focuses on the use of—

(1) Performance specifications, which describe how a product is to work but not (in contrast to design specifications) how it is to be made.

(2) Life cycle costing (LCC), which provides for contract awards for those products having the lowest total ownership cost for a given specification, as opposed to lowest purchase price.

(3) Value incentives clauses (VIC), which provide for a sharing with contractors of 50% of any cost saving innovations introduced into their products.

(4) System purchasing, in which a collection of distinct products intended to operate together as an entity (e.g., clinical laboratory, office building) is purchased under a single comprehensive performance specification.

(5) Initiative purchasing, in which the agency actively seeks or responds to product innovations which do not meet current specifications but appear to meet user needs.

ETIP is working with four different organizations in its procurement experiments:

1. GENERAL SERVICES ADMINISTRATION

The Federal Supply Service's $2 billion annual volume makes it the largest purchaser of civilian goods in the government. ETIP and the FSS are currently conducting and designing experimental procurements of power mowers, air conditioners, hot water heaters, kitchen ranges, refrigerator-freezers, typing and printing ribbons, chemical cleaning compounds, clothes dryers and washers, pocket calculators, industrial batteries and dry cells, paints, floor scrubbers, compact sedans, and floor coating systems. Each procurement experiment lasts three years so as to give suppliers sufficient lead times to plan significant innovations.

In order to facilitate the use of LCC and VIC throughout FSS, ETIP has provided assistance for the development of LCC and VIC training courses, the first series of which has already been taught. ETIP is also helping FSS develop systematic procedures for assessing user needs and translating these into appropriate specifications.

ETIP and the Public Building Service are engaged in the development of an LCC methodology for general use in the planning and acquisition of federal space. This model will be used for the first time this coming summer in three different space requirement situations, and when refined is expected to be used by PBS for predicting building obsolescence, for making rent vs. construction vs. renovation decisions, and in evaluating contractor bids, for the entire $2 billion annual PBS volume.

2. VETERANS' ADMINISTRATION

The VA's $400 million annual purchases of medical goods makes it the largest single health care buyer in the U.S. After a year of intensive planning, the VA and ETIP will this spring launch a series of procurement experiments involving several dozen different products and the opening of an Experimental Procurement Office in the VA. These experiments are significant in that they will give heavy emphasis to the use of performance specifications while the FSS experiments emphasize LCC and VIC. This is because VA buyers work closely with the people who use the products and hence have a better feel for desired performances than do GSA buyers whose customers are in other agencies.

Among the experiments to be conducted are the establishment of an active system to identify and screen new products for incorporation into VA purchasing plans, and another system for identifying emerging medical technologies whose commercialization can be encouraged by a guaranteed initial buy.

3. STATE AND LOCAL GOVERNMENTS

In cooperation with the Council of State Governments/National Association of State Purchasing Officials, ETIP has established an experimental program aimed at eliminating duplications of effort in specification and test methods development, increasing the use of LCC and performance specifications, eliminating ordinances requiring the acceptance of least-cost bids, and developing and using consensus standards, specifications, and test methods. Four regional meeting of State purchasing officials have been held, and a long list of products for experimentation has been developed. A similar experiment dealing with local governments will be initiated this spring. Together, State and local purchasing of civilian goods amounts to some $100 billion annually.

B. Regulation

ETIP's regulatory interests focus on four activity categories:

(1) Standards regulation, in which a firm must assure that a product meets specified standards before it can be sold or used.

(2) Certification regulation, in which a government license is required for sale or use.

(3) Economic regulation, in which rates and service requirements for entire industries are established.

(4) Envelope regulation, in which the limits of acceptable business practices are defined (e.g., antitrust).

In general, regulatory chances that might stimulate technological change can be pursued through:

(1) Legislative change.

(2) Agency-initiated administrative changes.
(3) Litigation before the agency in formal proceedings.

ETIP's regulatory proceedings in general focus on (2) above, but in some cases are expected to lead to (1) and (3).

In pursuing its regulatory interests, ETIP is seeking the following general changes:

(1) Accelerate and improve the quality of regulatory standards development to reduce uncertainties and delays in the regulatory process.

(2) Increase codification of and otherwise facilitiate the meeting of certification requirements to reduce uncertainties, unnecessary compliance costs, and delays.

(3) Design rates and rate structures to be more reflective of the current economic needs of the marketplace.

(4) Improve the definition of "envelope" boundaries to afford business maximum freedom of operation within allowable limits.

ETIP is working with a number of regulatory agencies in pursuit of its goals.

1. FEDERAL RAIL ADMINISTRATION

Much of the current assault on economic regulation is based on the untoward and uneconomic results which have stemmed from it rather than from its inherent structure. The thesis of this experiment is that a considerable amount of these troubles has arisen from an inability of the regulatory process to examine in considerable detail and sophistication the cost structure of the aspect of an industry under regulation, with the result being that the cost and benefits are so dislocated that the entire system becomes highly inefficient. Thus this project is examining a particular cost and logistics structure in considerable detail in an effort to see if that information can successfully be used to structure the regulation which allocates the costs and benefits so that the industry responds to the market rather than to the artificial constraints of regulation.

The particular topic of the experiment is transportation of fresh fruits and vegetables from the western growing regions to the markets of the east. It will generate an extensive amount of information about the way they are grown, processed, transported, distributed, and marketed in an effort to determine the various costs and benefits of alternative systems. That information will then be used in the regulatory process in proceedings before the Interstate Commerce Commission. This is expected to occur in the fall of 1976.

2. NUCLEAR REGULATORY COMMISSION

For the fulfillment of their duties, many regulatory agencies must develop and promulgate highly technical standards. These standards are inevitably based on the state of technology of the relevant area, and it is these which provide the direct interface between technology and regulation. One way of developing these standards is by means of the traditional manner of establishing consensus, or "voluntary", standards. These are developed outside the agency by a committee of people with a practical familiarity with the subject matter and, once developed, they are tendered to the agency for incorporation into its regulatory scheme.

This experiment, run in cooperation with the NRC and the American National Standards Institute, makes several changes in the normal way these consensus standards are developed to see if their development can be expedited and the information underlying them increased. It is testing the use of a full-time committee chairman instead of the normal case of having someone do the work in their spare time. Another aspect is to provide technical editorial services for the preparation of early draft standards; another is to provide a committee with technical secretarial help to expedite the translation of committee discussion into draft standards. Finally, it will bring a committee together for an extended period of time by paying out of pocket costs in an effort to substantially reduce the amount of time consumed by coordinating views via the mail, telephone, and through shorter meeting periods.

If some, or all, of these processes substantially reduce the amount of time required for the development of a standard, or if they substantially aid in providing technical information for the formulation of better standards, then there will be justification to attempt to use these processes on an ongoing basis in the many agencies which promulgate technical standards.

This experiment will be concluded this coming summer. It is expected, however, that significant interim results will be obtained within a few weeks.

3. OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

This project, like the foregoing, experiments with the setting of highly technical regulations. While the NRC experiment concerns standards developed outside the agency and tendered to it for adoption as a regulation, this one concerns standards developed inside the agency by the traditional administrative process.

During the process of setting the highly technical standards which concern employee safety and health a number of factors must be taken into account—technical feasibility, economic effect of different levels of protection, the worker's psychological reaction to a requirement, and the ability to administer the requirement without protracted litigation. In order to do this, information must be developed on each of these areas and its nuance and implication analyzed and understood. Thus it is essential that all available information be incorporated in this process. But even the information now presented in the proceedings leading to the development of a standard can be vast and consequently difficult and time-consuming to master.

This project will use modern information handling technology in an effort to increase the amount of data available for the setting of standards, to increase the amount of participation in the standards setting process, and to expedite the handling of all the information generated. While the system designed for this experiment is of particular relevance and concern to OSHA, the results of the project should be of interest to other situations in which agencies develop highly technical standards (as well as other, routine administrative procedures) in-house

4. ENVIRONMENTAL PROTECTION AGENCY

EPA is in the process of implementing a new scheme for the regulation of pesticides. This scheme is expected significantly to increase what is already an extraordinary amount of money and time to comply with the testing requirements that are necessary for approval by EPA. The fear is that these factors, along with other regulatory problems, will discourage the development of new pesticides and other forms of pest controls. Many of the same problems are encountered in other regulatory settings, especially where a product must be approved by an agency before it may be marketed. The results of this experiment should thus be widely applicable.

This experiment is examining and will then test actions the Federal Government, and in particular EPA, can take to reduce the high costs of complying with the regulations and will determine what might be done to otherwise provide an incentive for the discovery, development, and use of new pest controls. As part of this project, a forum of interested parties will be convened to discuss the findings of the study. The hypothesis of the project is that this detailed examination of incentives, followed by a forum to discuss the implications of the various alternatives examined in the study, is a mechanism which will facilitate the adoption of changes which will provide incentives for innovation in this important field.

Among the changes being examined are: the certification of non-federal laboratories for product testing; federal testing; increased codification of certification requirements; the use of a revolving fund to shift certification costs from front-end to downstream based on royalties; and the use of crop insurance rather than pesticides in some instances. EPA is expected to be actively involved in the application of these changes by summer.

5. FEDERAL POWER COMMISSION

During the process of the regulation of electric utilities by the 50 State Public Utilities Commissions vast amounts of information must be gathered, quantified, analyzed, and processed before a hearing on a rate adjustment can be held. Once the hearing has been conducted, all the information provided there must be taken into account and a final determination made as to the rates. All this requires a long time, so that by the time the process is complete, the information is frequently up to three years old. In relatively stable times, this staleness is not of dire consequence. But in times of high inflation and changing energy requirements, it can seriously disrupt the market and cause severe hardships for utilities.

Indeed, the Nation's electric utilities are currently investing in generating capacity at a rate that is only half of that needed to meet demand ten years from now. To alleviate some of the problems stopgap measures have been taken which provide almost no incentive to the utilities to invest in new efficient equipment or to use fuels more efficiently.

In this experiment the FPC and two or three state public utility commissions (negotiations are underway with California, Ohio, and North Carolina) will experiment with the use of computers to substantially expedite the process involved with rate adjustments. It will also experiment with alternative rate structures, to ensure that the price consumers (residential, commercial, and industrial) pay for electricity reflects the long term marginal cost of providing it to them.

6. FOOD AND DRUG ADMINISTRATION

In an experiment expected to be initiated this spring with the FDA, new mechanisms will be tested for accelerating the introduction of new pharmaceuticals into the marketplace. At present, new drugs are tested for safety and efficacy before they are licensed. Once the license has been obtained, no further information is sought about a drug unless a problem arises. It is anticipated that this experiment will test a procedure whereby only safety testing is conducted before a license is granted, and efficacy testing will be conducted by obtaining information from physicians who are using it on a limited scale. This should both accelerate the introduction of new drugs and provide a larger population sample for more thorough efficacy testing.

7. ANALYSIS OF REGULATORY CHANGE DYNAMICS

This is a collection of case studies, contracted for by ETIP, which will analyze the processes and procedures which were involved in the change (or proposed change) of regulations which have had (or would have had if adopted) a significant effect on innovation. Particular attention will be paid to where the idea for the change occurred, the nature of the proceeding, who the interested parties were and what were their positions, the nature of the evidence presented, and so on.

The purpose of this study is to gain insight and documentation with respect to the political forces leading to regulations. This is deemed an important contribution to any effort which would be used, on an on-going basis, to provide the maximum responsiveness of regulation to economic and technological needs.

C. Civilian Research and Development

ETIP's interests in R&D focus primarily on federally-sponsored applied R&D which is intended to lead to the development of manufactured goods for sale to non-federal users. This represents an estimated $5 billion annual expenditure.

In pursuing its R&D interests, ETIP is seeking to:

(1) Describe current policies and practices regarding the pursuit of R&D.

(2) Define and test alternative policies and practices that would improve the application of R&D results.

ETIP's R&D activities are focused in a few key studies and experiments.

1. R. & D. CRITERIA

A retrospective analysis of civilian R&D programs which is examining the reasons for selecting R&D (as opposed, e.g., to regulation) as a policy instrument and on the "policy history" of civilian R&D activities. This and the following study will be completed next winter.

2. DEMONSTRATION PROJECTS

A similar analysis of federally-funded demonstration projects, which is intended to provide criteria for selecting these as useful technological-change policy tools, and guidelines for their effective pursuit.

3. R. & D. MANAGEMENT

A study designed to describe, categorize, and compare current federal R&D agency practices in order to understand how that R&D is guided toward its stated objectives; and to develop a set of practical guidelines for R&D planning, project selection, resource allocation, and evaluation, all with the sim of improving the application of R&D results. This work will be completed in the summer of 1976.

4. EXPERIMENTS

A set of R&D agency experiments, now being designed, that will see the establishment of formal R&D planning functions in a number of agencies, the purpose again being to improve the application of R&D results. These experiments will last three years.

D. Small Business

Two activity categories are of interest to ETIP in this context:

(1) The availability of capital for small technology-based firms.

(2) Disproprotionate regulatory compliance costs for small technology-dependent firms.

The following projects are currently underway:

1. SMALL BUSINESS ADMINISTRATION–EVALUATION PROCEDURES

In this project, procedures and criteria are being developed and will then be tested for the evaluation of SBA loan applications containing an element of technological risk. At present, such applications are rejected by the SBA.

2. SMALL BUSINESS ADMINISTRATION—COMPETENCY EVALUATIONS

Procedures and criteria are being developed and will then be tested to improve the use of small R&D contractors on federal small business set-asides. At present, no formal criteria exist for making such set-asides.

3. SMALL BUSINESS ADMINISTRATION—REGULATORY COMPLIANCE

Procedures are being developed and will then be tested to help small firms required by regulations to undergo technological change.

4. CONNECTICUT PRODUCT DEVELOPMENT CORPORATION

In this experiment, CPDC is testing a process pioneered by the National Research and Development Corporation of the U.K. The process provides product development funds to small firms that have exhausted their own resources for the purpose, in exchange for royalties based on future sales.

E. Financial Assistance

ETIP is conducting a comprehensive analysis of Federal programs that provide financial assistance to industry and to state and local governments, for the acquisition or operation of capital goods. One purpose of the study is to determine how such financial assistance might better be employed to stimulate, or to avoid inhibiting, desirable technological change. Another purpose is to identify and describe alternatives to financial assistance that might offer more cost-effective means to the same end.

III. Prognosis

While early measures of progress are exciting, substantial efforts are still required to carefully manage ETIP experiments and to initiate new experiments to fill important gaps, if the real benefits of the program are too realized.

As ETIP, NBS, and other elements of the Government gain confidence in the value of the policy development process ETIP is pioneering, there are growing needs and opportunities to apply this process to new problems and issues as they arise.

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