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INTERNATIONAL COMPETITION IN ADVANCED INDUSTRIAL SECTORS: TRADE AND DEVELOPMENT IN THE SEMICONDUCTOR INDUSTRY

A STUDY

PREPARED FOR THE USE OF THE

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LETTERS OF TRANSMITTAL

FEBRUARY 10, 1982.

To the Members of the Joint Economic Committee:

I am pleased to transmit a study entitled "International Competition in Advanced Industrial Sectors: Trade and Development in the Semiconductor Industry." The semiconductor study was prepared by Michael Borrus, James Millstein, and John Zysman of the University of California at Berkeley.

The American semiconductor industry is the key to the burgeoning American market in computers, robots, automated office equipment, avionics, telecommunications, and a wide range of other electronic products. The authors point out that this is an area in which government policy can have a decisive influence on the creation of comparative advantage in semiconductors. Although the United States remains strong in advanced industries, several developing countries, Europe and especially Japan, pose a challenge to continued U.S. strength in the high technology area.

The study compares the development of the semiconductor industry in the United States and Japan. Building on the leverage afforded by Department of Defense contracts, the United States developed an industry structure composed partly of companies that used semiconductors in their computer or other products, partly of innovative firms that focused on development and manufacturing semiconductors themselves, and two integrated giants, A.T. & T. and IBM, that developed and manufactured semiconductors for use in their own vast networks of telecommunications and computer products. All three were vital components that have led to the rapid growth of the industry.

The authors detail the contributions made by the small firms that specialized in manufacturing the semiconductor. The rapid expansion of the market for semiconductors brought prices down rapidly. The revenues from standardized products were plowed back into research and the next leap forward in capacity, versatility, and quality.

The competitive nature of the markets for many products that incorporate semiconductors led to the rapid diffusion of each advance in semiconductor technology. Constrained by antitrust considerations, A.T. & T. and IBM did not directly participate in the semiconductor market. They were active, however, in acquiring new technologies and in disseminating their own. They also served as the training ground for many of the scientists and engineers who later entered the semiconductor field with their own, smaller firms.

The semiconductor industry has been highly competitive for many years. It was only in the 1970's, however, that foreign producers, principally those in Japan, became a major factor in the American market. The authors describe the very different nature of the Japanese semiconductor industry. The Japanese government played a major role in building a successful industry in the largely protected Japanese market. In contrast to the proliferating manufacturers of semiconductors in the United States, the Japanese industry remained concentrated in the six large integrated electronics firms.

Unlike the American firms that have thrived on rapid product innovation, the Japanese have focused on reducing the price and improving the quality of large volume standardized semiconductors. In the view of the authors, Japanese competition in the standardized portion of the market threatens to eliminate the profits that have funded the research of the independent firms. The authors contend that the dynamism and the very structure of the American semiconductor market are under severe pressure.

In a concluding section, the authors spell out their own program to maintain the independent producers of semiconductors. The authors suggest a government commitment to maintain the conditions in which the dynamic firms can thrive. In their view, the United States must help provide a skilled workforce, fund an adequate level of basic research, and assure the independent firms access to capital for research and to meet the rising cost of manufacturing equipment. The authors couple their domestic program with a call to concentrate U.S. trade policy on opening up foreign markets to U.S. semiconductor exports.

This pathfinding study suggests a set of policies tailored to our industrial future. Dr. James K. Galbraith, Executive Director, and Dr. Kent H. Hughes, Economist, supervised the study for the Committee. It should be understood that the views expressed in the study are those of the authors and do not necessarily represent the views of the Joint Economic Committee or of individual Members.

Sincerely,

HENRY S. REUSS,
Chairman, Joint Economic Committee.

FEBRUARY 4, 1982.

Hon. HENRY S. REUSS,
Chairman, Joint Economic Committee,
Congress of the United States, Washington, D.C.

DEAR MR. CHAIRMAN: I am pleased to transmit a study entitled "International Competition in Advanced Industrial Sectors: Trade and Development in the Semiconductor Industry." The semiconductor study was prepared by Michael Borrus, James Millstein, and John Zysman of the University of California at Berkeley.

All the views expressed in the study are those of the authors and do not necessarily reflect the views of the Joint Economic Committee or any of its members.

Sincerely,

JAMES K. GALBRAITH,
Executive Director, Joint Economic Committee.

ACKNOWLEDGEMENTS

This project has benefited from the time and assistance given by many people in the academic and industrial communities. In the university community we should particularly like to thank Peter Katzenstein, Chalmers Johnson, T. J. Pempell, and Kozo Yammamura, whose careful analysis helped us immeasurably. Early versions of the piece were widely circulated in the industry. We also appreciated the help of Warren Davis and Tom Henkelman of the Semiconductor Industry Association.

The project was funded over two years from a variety of sources. Had we lacked any piece of the funding, the whole would have collapsed. The first version of this study in the summer of 1980 was funded by the U.S. Department of Commerce, the Wells Fargo Foundation, and the Institute for Governmental Studies at University of California, Berkeley. The second version was funded by the Wells Fargo Foundation, the German Marshall Fund of the United States, the Joint Economic Committee of the United States Congress, and the State of California (Office of International Trade and the Commission of Industrial Innovation).

We should like to express special thanks to several people. Regis McKenna provided initial insight and access to the industry and continuing invaluable support throughout the project. Louis Coleman and Richard Rosenberg assured the completion of the project by providing funds from the Wells Fargo Foundation at a critical moment. Karin Beros and her staff at the Institute for International Studies provided support tempered by patience throughout the complex history of this effort.

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INTERNATIONAL COMPETITION IN ADVANCED INDUSTRIAL SECTORS: TRADE AND DEVELOPMENT IN THE SEMICONDUCTOR INDUSTRY

by

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with the assistance of
Aeton Arbisser and Daniel O'Neill

University of California, Berkeley
January 1982

Introduction

TRADE IN ADVANCED INDUSTRIAL SECTORS: THE CASE OF SEMICONDUCTORS

For over twenty-five years after its inception in the late 1940s, the U.S. semiconductor industry enjoyed a position of unchallenged technological pre-eminence and international market dominance. U.S. based firms retained international leadership through several stages of technological innovation, market growth, and the consequent restructuring of their industry. In the mid-1970s, however, that leadership was challenged for the first time by large multi-divisional Japanese electronics firms. The share of the world market for integrated circuits held by U.S. firms declined between 1974 and 1978, while the Japanese share grew. As the U.S. International Trade Commmission (ITC) concluded, "much of the increase in Japanese market share was gained at the expense of U.S. producers."[1] Then, in the late 1970s, these Japanese producers captured a significant percentage of the domestic U.S. market for large-scale integrated circuit memories (LSI-MOS).*

These events signify much more than a loss of profits for U.S. firms in particular product categories in a single industry. They indicate the potential for an irreversible loss of world leadership by U.S. firms in the innovation and diffusion of semiconductor technology. Because the products of this industry are the crucial intermediate inputs to all final electronics systems, competition in the semiconductor industry will be at the center of competition in all industries which incorporate electronics into their products and production processes. Indeed,

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* For definitions of technical terms and abbreviations, see the Glossary, pp. 179-183.

trade in integrated circuits and electronics in general is typical of competition in industrial goods between the advanced countries. Market success in the products which these countries exchange between themselves depends on the management of complex processes of product development and manufacturing rather than simply on national differences in factor costs such as wages or raw materials. The corporate capabilities that afford a national advantage in high technology can be promoted by government policies for industry and trade. National competition in this industry is typical of the trade conflicts we may anticipate in all of the growing high-technology industries on which all advanced contries are depending. Indeed, the case of this one industry suggests that government policies can shape a nation's comparative advantage in trade. General issues aside, however, we shall argue that the outcomes of industrial competition in electronics will have a unique national importance.

For two generations, analysts have foreseen a new industrial revolution based on the processing of information. Although the computer has been the symbol of this transformation, the semiconductor has in great measure been responsible for it. Innovation in and diffusion of semiconductor technology has helped to create markets in data processing, automated production, and robotics; and it has fundamentally altered communications, instrumentation, transportation, consumer goods, and military systems. The videogame may be no more than a new diversion, but the automated factory portends fundamental changes in the organization of work. The semiconductor industry is therefore strategically vital to the future growth of knowlege-intensive industrial development within the U.S. economy. For the foreseeable future, the relative economic strength of all advanced industrial economies will rest in part on their capacity to develop and apply semiconductor technology to product design and production processes. Thus the loss of leadership in this one industry would mean the loss of international competitiveness in many of the advanced technology sectors that have been the basis of a U.S. advantage since the Second World War. This study therefore analyzes the evolution of competition in an industrial sector that will undoubtedly remain an important focus of international negotiation for many years.

The most salient measure of the U.S. semiconductor industry's competitive performance has been a constant and steady decline in the price of an electronic function, for example, from $15.00 in 1965 to 2 cents in 1980. (The consumer's interest is best defined as the cost of an electronic function and the extension of the tasks that electronic systems can perform.) This remarkable performance has been based on the creation of new products rather than the more efficient production of existing products. It is the steady advance in technology that has made possible the dropping cost of components and the expanding pool of applications. For example, there are limits to the reduction in costs and applications of discrete semiconductor components, whatever efficiencies in production might be achieved. Advances in production technology and the resulting cost competition between producers of the standard product of the moment have stimulated product technology, as some companies have tried to avoid price competition with product innovations. The foundation for this dynamic advance has been a distinctive structure of the U.S. semiconductor industry. For the purposes of this study, there are three critical components of that structure: (1) the set of independent, so-called merchant semiconductor producers; (2) the set of electronic systems producers who incorporate the merchants' products as intermediate inputs; and (3) the two largest systems producers, ATT and IBM, who have played a crucial role through their broad-based, widely shared research and development.

The merchant firms have given the industry its dynamism, for their central advantage over larger-scale systems producers has been in continuously advancing existing component technologies and introducing them into new uses. In providing an ongoing stream of competitive component innovations, these firms have forced final systems producers to be similarly competitive in the speed and inventiveness with which they incorporate component innovations into their final products. It is, then, in this central role as innovators and diffusers of semiconductor technology that the merchant producers have contributed to the advance of the knowledge-based sectors of the U.S. economy. Their capacity to sustain their entrepreneurial role through successive stages of the industry's development has rested in the most widely accepted view on achieving a <u>commodity</u> position for the products they innovate. These products must achieve a widespread use that permits volume production; the innovating firm must capture a substantial part of the mass market if it is to have sufficient returns to help finance the next round of innovation and diffusion. Some firms, by contrast, have found a niche in specialized market segments, which together represent nearly 40 percent of open market sales, and have succeeded without participating in the commodity market. It is our view that a strong national presence in the commodity semiconductor markets is still required to maintain the pace of advance in the underlying technologies on which all firms depend. The issue is significant because the Japanese challenge, as we shall discover in Chapter Three, is primarily in standard commodity products, albeit products of enormous sophistication. American firms have been most successful in responding to rapidly shifting market needs, while the Japanese have had their greatest success in the more standard products in established markets. The challenge is all the more serious since the industry has become increasingly capital intensive, which favors Japanese capacities and strains some American firms.

ATT and IBM have played a special role in the semiconductor industry's dynamism. That role is a by-product of their effort to preserve their existing final product advantages through extensive research and development. Since neither firm competes in the merchant component market -- a result of court decree or corporate choice informed by antitrust considerations -- both have incentives to trade their technologies for technological developments made by other firms. Such exchanges serve to protect ATT and IBM against radical breakthroughs elsewhere in the industry, and serve simultaneously to spread their own technological advances to the merchant sector.

The structural linkages between ATT, IBM, the merchant firms, and the set of systems houses are unique to the U.S. industry. It is doubtful whether the dynamic character of the industry's competitive performance -- the constant development of new applications and markets -- could have been sustained without each component. In addition, the U.S. government has played an important, and initially determinative, role in the industry's development. However, that role is best characterized as one of indirect influence through tax and military policies. Whether that role is sufficient to help sustain the industry's dynamic character in the future depends upon our evaluation of the competitive threat the U.S. industry faces from abroad.

Japanese entry into the U.S. market is part of a conscious national strategy of establishing comparative advantage in the knowledge-intensive and technology-intensive industries. The 300-page Vision of MITI Policies in the 1980s is explicit about this goal: "It is extremely important for Japan to make the most of her brain resources, which may well be called the nation's only resource, and thereby to develop creative technologies of its own. . . .Possession of her own technology will help Japan to maintain and develop her industries' international superiority and to form a foundation for the long-term development of the economy and society. . . .This spirit of basing national development on technology should be our aim in the 1980s."[2]

This developmental goal is really an evolution of Japan's general ongoing policy of promoting economic development, which could be seen in shipbuilding, steel, and automobiles a generation earlier. Developmental strategies organized around closure of Japanese domestic markets and promotion of Japanese production became more than tactics for nourishing infant industries. In an economy dependent on the export of manufactures to pay for raw materials, MITI chose industries for domestic development that could serve to expand overseas sales. The Japanese system became one of controlled competition, a system of a managed but unstable competitive equilibrium. Intense competition between firms in targeted sectors was directed and limited both by state actions and by collaborative efforts of the firms and the banks. State bureaucrats did not dictate to an administered market; rather, they consciously manipulated market forces to shape the development of particular sectors.

The Japanese created a system in which, when it works at its best, the state helps in a detailed way to establish conditions of investment, risk, and collaboration that promote the long-term development and international competitiveness of favored industries. As we shall demonstrate in this essay, the structure of the Japanese domestic market provides domestic electronics producers substantial advantage in international competition. To the extent that arrangements in the Japanese market which favor domestic producers are the result of conscious policies of the government or the corporations, these arrangements represent political tactics of industrial development and should be made the subject of international trade negotiation.

During the 1970s, the Japanese electronics and semiconductor industry moved from a consumer product orientation and a technological position of relative inferiority in components toward a state-of-the-art capability in components, telecommunications, and computers. State policies helped to protect, promote, and rationalize the industry. High-volume production of commodity components manufactured with U.S.-made production equipment to U.S. design standards characterized the successive stages of this transformation. (Indeed, for their production of advanced devices the Japanese still rely heavily on U.S. equipment in some manufacturing stages and still tend to follow U.S. design standards.) Stable sources of plentiful capital for expansion and high volume production in a closed domestic market, a market rationalized among firms in both their component and final systems production, served finally to leverage Japanese export penetration of the U.S. market. Such structural characteristics also served to cushion the Japanese industry from technological or market errors. Japanese firms could compensate for the consequences of a market misjudgment or of a new U.S. technological innovation by returning to a Japanese domestic market insulated from foreign competition. Formal and informal control over the degree and character of foreign access to the domestic Japanese market prevented U.S. firms from consolidating their innovations and victories in the international marketplace and translating them into entrenched positions in the Japanese market.

Certainly the structure of the distribution system and other features of the Japanese economy represent "natural" obstacles to foreign penetration, but there can be little doubt that government and corporate policy reinforced this closure. Although direct discrimination is now being reduced and direct government administration of the economy is receding, the arrangements that give structural advantages to the Japanese have endured. It should be understood that these arrangements were not produced by a backward economy, an infant industry, or small-scale firms in need of protection. Rather, by the end of the 1970s, all of the top six electronics firms in the heavily oligopolistic Japanese semiconductor industry were multi-billion dollar companies. Thus the story of Japanese electronics development is as much a political story as a study in marketplace competition.

In sum, the Japanese companies have emerged as strong international competitors in semiconductors by enjoying the benefits of a state that organized its relations with the business community and tried to structure the market to promote accelerated economic development. State policies and private market arrangements established a relatively stable and predictable domestic market environment. In this environment, large integrated firms have prospered in international markets chiefly with production strategies that focus competition on cost and quality of commodity products rather than with entreprenurial strategies that focus competition on the diffusion and advance of new technologies and the rapid adjustment to shifting markets.

The implications of this analysis are that the Japanese have emerged as strong international competitors in semiconductors, with unique production strengths and market strategies based on Japan's domestic market structure. The medium-term Japanese competitive threat is to the merchant sector of the U.S. industry. By bringing their high-volume production strengths to bear in competition for large shares of merchant semiconductor markets in commodity products in an increasingly capital intensive industry, Japanese firms could come to dominate U.S. component commodity markets; they could deny U.S. merchant firms the margins that have historically underwritten their capacities to create new products and make new markets. Thus, over the long term, significant Japanese domination of merchant commodity markets -- if it occurs -- might well rob the U.S. electronics industry of the unique capacity for innovation and diffusion that has been the hallmark of its merchant firms. If the U.S. semiconductor sector, where relative advantage lies in dynamic interaction between merchant firm and user, loses its markets to the Japanese firms whose relative advantage lies in production efficiencies in commodity products, the pace and character of innovation throughout the U.S. electronics industries could well be slowed. The most serious damage of a loss of competitive advantage in integrated circuits would be that the integrated Japanese electronics companies -- which produce both components and final systems products -- would come to dominate systems markets over the very long run.

The character of the Japanese threat in this industry, however, should not be overstated. Nor, indeed, should U.S. policy be based directly on countering the potential threats outlined above. Markets for semiconductor technology are expanding at such a rapid pace that there may well be room for all competitors. Moreover, as a relatively young, dynamic sector serving growing markets, the U.S. semiconductor industry is vastly different in kind from the mature, relatively uncompetitive domestic U.S. industries that succumbed to competitive pressures from Japanese firms during the 1970s. Whereas other U.S. industrial sectors like steel have sought protection, this industry with its unique structure retains a dynamic ability to outstrip static Japanese advantages in production of a stable product line. Integrated-circuit technologies (IC) are young, rapidly changing, and still overwhelmingly the product of U.S.-based research and development. The issue which U.S. policy must confront, then, is how to reconcile Japanese and European ambitions to create internationally competitive electronics sectors with

U.S. interests in maintaining technological and marketplace leadership.

The United States has a clear strategic interest in retaining leadership in the semiconductor industry and in maintaining an industrial structure that has facilitated the diffusion and innovation of this most vital technology. There is simply no reason to allow the evolution of this sector to be dictated by the policies of foreign governments. This paper suggests policies aimed on the one hand at easing domestic constraints on the U.S. industry's ability to grow and compete, and on the other hand at opening international markets in Japan and the EEC to rigorous competition from U.S. firms. Such policies would serve to make domestic and international markets work more efficiently. If, to remain viable in the face of policy strategies abroad, U.S.-based firms require U.S. policies that ease constraints and open foreign markets, then failure to adopt such policies could generate serious long-run costs to the U.S. economy. If U.S.-based firms do not in fact need assistance, then the policies suggested here would serve only to facilitate market developments already underway and to speed the arrival of an electronics era. In this context, it is our view that American defense procurement can no longer play the catalyst role of guaranteed first user. Competitive civilian development of advanced technology will not emerge in some automatic fashion from defense expenditures.

More generally, events in the semiconductor industry provide the United States with a timely opportunity to reconsider U.S. policy responses to the generic problem of foreign governmental promotion of specific industrial sectors. Foreign growth policies aimed at accelerating the shift out of agriculture into capital-intensive industries (such as autos) were acceptable in an era of U.S. economic hegemony, but they pose new problems when they serve as strategies to forge leadership in the advanced technology sectors upon which the U.S. future rests.

The United States must not copy foreign growth strategies developed by other cultures for their particular national circumstances. Rather, working within the constraints of the U.S. political economy, the goal of policy should be to assist U.S. firms to compete successfully in international markets while equitably dispersing at home both the benefits of successful competition and the costs of adjustment. In an industry like semiconductors where the U.S. leads, such government action will be much less costly than the significantly more intrusive intervention that would be required later were the U.S. to lose its leadership.

This essay is a study of domestic development and international trade competition in an increasingly important American industry. It tells three interrelated stories. First, it details the evolution, operation, and distinctive character of the U.S. and Japanese semiconductor industries (Chapters One and Two). National differences in the relations between government and industry, we shall discover, have massive consequences when corporations compete in international markets.

Second, it describes how the Japanese utilized a controlled domestic market and financial leverage to enter the U.S. market in the late 1970s; it evaluates the character of U.S. and Japanese competitive interaction in the U.S. market, and draws out the implications of this interaction for the U.S. industry's ability to retain its technlogical and market leadership (Chapter Three). The trade battle in this essential industry is as much a political struggle between government policies of protection and promotion as it is a marketplace struggle between firms. Indeed, this case is prototypical of the industrial sectors in which the advanced countries will compete in the future and also of the type of trade politics that will be generated.

Third, the concluding chapter considers how U.S. policy might reconcile U.S.

interests in maintaining leadership in this industry with Japanese and European ambitions of sustaining their own industrial expansion in an epoch of electronics. Such a policy will have a trade component and domestic policy component. The trade policy needs of this industry, it should be noted, are often opposed to the types of policies demanded by the more traditional industries such as textiles, steel, and even automobiles. The political question for domestic policy is how the needs of American high technology sectors for open international markets can be reconciled with the demands of mature industries for various forms of protection. There should be little doubt that American policies of selective protection in sectors where we are weak internationally make it harder to insist on policies of open trade in sectors where we are strong. In the early years domestic policy for the semiconductor industry meant on the one hand Defense Department procurement and product development, and on the other hand antitrust policies, formulated without direct reference to the development of the industry, which established the unique role that ATT and IBM were to play. As the industry developed commercial markets that outstripped defense procurements both in dollar volume and technological importance, the industry focused its attention on the market, not on Washington. Now, under pressure from Japanese competitors building on a more concerted national effort, domestic policies to support U.S. electronic development are again needed.

Chapter One

THE DEVELOPMENT OF THE AMERICAN SEMICONDUCTOR INDUSTRY

Since the inception of the integrated circuit at Texas Instruments and Fairchild in 1958, the United States has dominated the development and marketing of integrated circuit devices. Technological innovation in integrated circuit design and production processes has kept U.S. firms at the leading edge of growth in the world market for integrated circuits. In 1980, U.S. firms still accounted for 70 percent of the world's production of integrated circuits.

The international competitive advantage that U.S. firms have enjoyed in the design and production of integrated circuits has stemmed, in large measure, from the early developmental trajectory along which the industry was pulled. From 1958 to 1964, product development support and volume demand from both the United States Department of Defense and the National Aeronautics and Space Administration created a "market pull" effect on the initial phase of integrated circuit development which spawned new entry and sped the commercial diffusion of the new technology. Defense and space program procurement in the early 1960s offered an assured demand for the integrated circuit at premium prices, which helped to underwrite the risk and cost of product development in the private sector and served to broaden the industrial base over which technological innovation in integrated circuit design and production continued to advance.

It should be noted, however, that while early defense and space administration demand for the integrated circuit was the most direct stimulus to industrial growth, other environmental factors that were unique to the United States domestic market shaped the structural impact of this early government support. Ready availability of venture capital, a high mobility of technical personnel between firms, liberal licensing of transistor and integrated circuit technology by the U.S. firms which had pioneered their developments, as well as antitrust constraints on potential ATT and IBM entry into the open market for microelectronics, all contributed to the creation of a domestic environment in which new entry and competition were fostered by the initial demands of the defense and space programs.

After this first stage in the industry's development, the factors sustaining the early pace of integrated circuit innovation and diffusion in the United States rested with the unique industrial structure and commercial market dynamism which demand from the military and space markets had fostered. In both Europe and Japan, integrated circuit production is dominated by large, vertically integrated electronic systems manufacturers; in the United States the bulk of integrated circuit production has been carried out under the auspices of an independent set of "merchant" firms, whose primary business is the manufacture and open market sale of microelectronic components. These merchant producers have been a crucial stimulus to a technological and competitive dynamism unique to the United States integrated circuit industry.

The integrated circuit industry's historical development has been strongly influenced by the markets which, over time, it has served. As we have noted, early government development support and market demand for integrated circuits helped to pull the U.S. microelectronics sector into the production and design of integrated circuits well in advance of microelectronics producers in Europe and Japan. Thereafter, demand from a more highly developed computer and industrial electronics equipment market in the United States helped to sustain the pace of innovation and market growth for integrated circuits; despite military procurement during the Vietnam war, the role of "creative first user" of the latest in integrated circuit designs fell to the commercial market. Demand from the computer and industrial markets in turn spawned a new wave of merchant entrants into the production of integrated circuits. Between 1966 and 1972, over thirty new IC firms entered the domestic market.[1]

To focus simply on the demand-pull effects of the military and computer markets on innovation and sales growth in the U.S. integrated circuit industry is to lose sight of the dynamics of competitor between IC manufacturers, and particularly between the merchant firms that set the pace of technological advance. Product and process innovation and competitive interaction among the merchant firms have fostered a progressive reduction in the cost and enhancement of the performance of an electronic function. As competition on cost and performance drove the price of an electronic function progressively downward, the elasticity of demand for integrated circuits became greater and greater; by achieving commodity positions as market demand for the latest in IC device technology expanded, the "merchants" earned a sufficient return on their risk-taking to help finance the next round of product innovation and market development. Thus competitive rivalry between the merchant firms themselves as well as between the merchants and the more established vertically-integrated electronic systems companies such as RCA, Westinghouse, and General Electric, accelerated the pace of both <u>innovation</u> in and <u>diffusion</u> of integrated circuit technology. As an independent, low-cost source of advanced IC technology, this unique merchant segment had the dynamic effect of introducing new competitive risks into the environments of established component and system producers. By lowering technological barriers to entry in systems markets and creating the potential of new cost and product performance competition in those markets, the merchants altered the technological and competitive environment of dominant electronic system manufacturers such as IBM and Western Electric, creating greater uncertainty and greater competitive rivalry in the market for electronic systems. The presence of the merchants had the dynamic effect of enhancing the pace of IC innovation and diffusion across the domestic economy as a whole.

The merchant segment of the industry which fully blossomed in the period 1966-1972 has been a shining example of two venerated features of competitive capitalism: the success of venture-capital backed entrepreneurship, and the triumph of the technological innovativeness of the small firm. However, to this day, perhaps the single most important contribution of the merchant producers has been their dynamic role in fostering increased competition in and proliferation of electronic systems markets. Indeed, as the United States confronts a changing environment in the world market for microelectronics, it is this competitive dynamism, unique to its domestic industrial structure which policy should seek to promote. For its competition across this structure that has produced technological progress and market diffusion in the United States and sustained the international competitiveness of the American electronics industry as a whole.

A third stage of the industry's development may be loosely associated with the development of large-scale integrated circuits in the early 1970s. Large-scale integration involved a change in the character of the product which integrated circuit firms produced; increasingly, as device geometries were reduced and packing densities increased, "components" began to incorporate basic features of what were previously regarded as entire electronic "systems." The most salient example of this was the introduction by Intel of the microprocessor in 1971. With the development of these more complex, system-like devices, the third stage in the evolution of the U.S. industrial structure began. On the one hand, "merchant" producers began to integrate vertically into one or more of a variety of final electronic "systems" markets in order to capture the high value-added of their more complex devices. On the other hand, both to assure supply for their final product demand and to give their final system products a competitive edge through custom circuit design, an increasing number of electronic system producers began to integrate backward, either by establishing "captive" integrated circuit design and fabrication capacities or by acquiring existing integrated circuit houses in the United States. In turn, beneath these different segments of "component" and "system" producers there grew up a developed infrastructure of materials suppliers and fabrication and test equipment manufacturers.

The current structure of the U.S. industry can be understood, then, as a composite of these three relatively distinct stages of its development. It is composed of (1) small IC "merchant" producers, such as Siliconix and Monolithic Memories; (2) large IC merchants such as Texas Instruments, Motorola, Intel, and National Semiconductor; (3) electronic systems manufacturers such as Hewlett Packard and Hughes; and (4) the two dominant vertically integrated systems manufacturers, IBM and ATT. The uniqueness of this industrial structure lies precisely in its broad technological base and in the diversity of both firm capacities and market strategies which this structured segmentation implies; its strength, rests upon the competitive dynamism which this structure has spawned. Thus foreign industrial policies or coordinated foreign firm strategies which threaten the dynamic operation of competition in the American market must be regarded as more than a threat to a particular set of U.S. firms in particular product markets; they must be seen as a threat to the dynamism of the American electronics industry as a whole. Leaving an evaluation of these matters to Chapters Two and Three, in this chapter we shall describe the historical development of the American industry and the structural underpinnings of its unique technological and competitive dynamism. This outline of the industry's development and structure will serve as a basis for describing how the current trade and development policy conflict between the United States and Japan has been generated by the structural differences between each nation's domestic sector.

I. Military Markets and Merchant Producers, 1958-1965

The specific technological direction of the U.S. industry was in large measure influenced by its early relationship with the U.S. military. The demand of the defense and aerospace markets pulled the industry along a specific technological trajectory and helped to prod the domestic sector into a position of market dominance and technological leadership. During the 1950s, while Europe and Japan pursued the development and mass production of germanium transistor-based consumer electronic systems, the United States industry, prodded by U.S. military demands for miniaturization and devices of higher performance and reliability, became pre-eminent in silicon-based technology.[2] As a recent Department of Commerce study of the industry notes: "Initial U.S. Government endorsement of basic semiconductor research and product procurement for defense and space needs made possible advanced silicon technology that laid the foundation of today's modern semiconductor industry."[3]

Perhaps the most important consequence of early defense sponsorship of silicon-based devices was its impact upon the structure of the electronics component industry. Prior to the invention of transistors, the dominant electronic component technology was the electron tube, and component production tended to be dominated by major multi-divisional electronic systems producers. The shift to the transistor and ultimately to the integrated circuit reshuffled the composition of the leading component manufacturers. Few of the leading producers of the electron tube managed to retain their component market positions in the new technologies.[4] In this reshuffling process, defense and aerospace procurement created a market incentive for entrepreneurial, technological risk-taking and thereby helped to spawn an independent sector of semiconductor component manufacturers. As Utterback and Murray conclude: "Defense procurement and support for R&D stimulated the entry of new firms in the electronics industry in several ways, primarily through direct purchases. By providing as initial market at premium prices for major advances, defense purchasers speeded their introduction into use."[5]

The early development of the integrated circuit is most noteworthy in this regard. The first integrated circuit was demonstrated by Texas Instruments in 1958. While developed without direct research and development funding from the U.S. government, in mid-1959 the Air Force awarded the company a $1.15 million, two and a half year contract to develop various integrated circuit devices. In December 1960 the Air Force followed its original award with a $2.1 million contract for the development of production processes and special equipment needed for the fabrication of integrated circuits in bulk quantities.[6] Asher and Strom report: "As late as 1961, the industrial and scientific communities still voiced doubts as to the worth of integrated circuits from an equipment and systems viewpoint. To alleviate these doubts . . . the Air Force proposed the building of a representative piece of electronic equipment using integrated circuits. Under Air Force sponsorship, the building of a digital computer was introduced into the Texas Instruments production program. Two identical computers were built: one with 9000 individual components and one containing only 587 integrated circuits."[7]

Meanwhile at Fairchild, without any government research and development funding, the development of the planar process moved the integrated circuit out of the laboratory and into production. For both Fairchild and Texas Instruments, the initial market in 1963 for integrated circuits consisted of two major government procurement programs: for Texas Instruments it was the Minuteman II missile guidance system and for Fairchild it was the Apollo spacecraft guidance computer. Between 1963 and 1965 the industry was awarded at least twelve other military and space electronic systems contracts calling for the incorporation of monolithic integrated circuits. In 1963, government procurement constituted 95 percent of the market for monolithic ICs, which had an average selling price of $50. In 1965, government procurement constituted only 75 percent of demand but the price per IC had dropped below $9. Over the three-year period, total IC production grew rapidly, from $4 million in 1963 to $80 million in 1965.[8] During this period new companies such as Signetics, Siliconix, General Microelectronics, and Molectro were founded primarily to manufacture integrated circuits. In turn, older electronics systems producers such as RCA, Sylvania, Motorola, Westinghouse, and Raytheon began to move, albeit more slowly, into volume production.

In the early development of integrated circuit production in the United States, the Department of Defense and the National Aeronautics and Space Administration played the role of "creative first users."[9] Pursuing their respective strategic objectives, their support had two effects: the first was the intended effect of encouraging and accelerating the pace of technological advance; the second was the unintended effect of fostering the development of a unique segment of "merchant" producers. This latter result could not have been predicted, but in terms of the long-run impact of early government support, it was perhaps the more significant of the two, for the merchant producers kept the pace of technological innovation and diffusion alive and thriving in commercial markets long after the strategic objectives of the military had been realized.

II. Dynamic Competition: The Computer Market and Merchant Competition, 1966-1972

After its auspicious beginnings under government sponsorship in the early 1960s, U.S. production of integrated circuits more than doubled between 1966 and 1972.[9] The rapid rate of growth in integrated circuit production during this period reflected, in large measure, a fast acceleration in demand from computer and industrial equipment manufacturers during the late 1960s. Whereas in 1965 military sales still constituted more than 55 percent of the total value of domestic IC sales, by 1972 some 65 percent of all IC sales in the United States went to the computer and industrial markets, and military sales fell to less than 25 percent of the market.[10] The age of data processing had arrived and the integrated circuit industry, formerly under military tutelage, broke away to supply the more prodigious demands of the computer and industrial markets.

The relationship between the integrated circuit and computer industries has been characterized by Ian Mackintosh as a classic example of "industrial synergism": "Just as the American computer industry growth has been critically dependent on the availability of ever-increasing numbers of improved ICs, so has the spectacular growth of the American IC industry depended to a very high degree on having a large, innovative and 'local' computer market avid to make use of its rapidly developing semiconductor capabilities."[11] Together, the demand from the computer and telecommunications markets helped the United States rapid growth by achieving a dominant international position in the design and production of the integrated circuit.

The infant computer industry in the 1950s had been an early market for discrete semiconductor devices. Because of the relative unreliability of tubes, transistors were rapidly assimilated into computer hardware design. In 1960 a large computer could easily contain over 100,000 diodes and 25,000 transistors.[12] Nonetheless, the shift to discrete semiconductor devices in the design of complex large circuits, while offering the advantage of greater reliability and speed, still entailed high assembly and connection costs.

In 1964 IBM introduced the first computer line not based on discrete semiconductor technology. The IBM System 360 incorporated a hybrid technology which packaged together several transistors and other devices to form an operating circuit. This hybrid design helped to reduce the cost of producing a computer, further reduced its power consumption, and increased its speed and capacity. With the introduction of user software that could be used on all models within the 360 line, the commercial computer market begain to expand rapidly.

IBM's competitors reacted to the System 360 with computer hardware based on the integrated circuit. The integrated circuit allowed for the design and production of an entire logic circuit on a monolithic chip of silicon. By packing fifty or more transistors on a single chip of silicon, transistor interconnection distances were dramatically reduced with the result that speed, power consumption, and reliability were all vastly improved. In turn, the integrated circuit eliminated much of the assembly cost associated with discrete and hybrid devices. As IC prices declined rapidly during the late 1960s and the functional complexity of the IC increased (both as an outcome of merchant competition), companies such as RCA and Burroughs turned to IC designs to lower their computer prices in the uphill battle for market share against IBM. On the basis of this new price competition, the domestic computer market entered a period of rapid sales growth.

In turn, advances in IC technology and their availability in volume from the merchant sector helped to spawn a new segment in the computer market: in 1965, Digital Equipment Corporation introduced the world's first minicomputer, the PDP-8. The availability of relatively low-cost integrated circuit logic chips from companies such as Texas Instruments and Fairchild helped to lower the capital and technological barriers to entry in the computer manufacturing industry. As a consequence, by the early 1970s minicomputers had become a high-growth and fiercely competitive market. The merchant integrated circuit industry also became fiercely competitive, as the firms strove through both cost-reduction and product innovation to pre-empt their competitors in the race for minicomputer designs that used their respective "families" of IC devices. During the 1960s "the computer industry's spectacular growth had been due mainly to its ability to produce equipment which would compute at ever-increasing speeds and reliability levels, and ever-decreasing costs and size, and essentially all of these attributes stemmed from advances in silicon technology."[13]

The evolution of integrated circuit design and fabrication started with the implementation of the basic logic gate and proceeded to the miniaturization of a complete computer subsystem, the microprocessor. This trajectory reveals a first principle of component-system interaction: as a component, the technological evolution of the integrated circuit has made it increasingly capable of implementing on a single chip basic features of what had previously been regarded as entire electronic systems. In the 1960s, early digital integrated circuit designs incorporated fewer than 50 transistors per silicon chip. As individual chips, the early digital integrated circuits needed to be connected to one another to perform computing functions. As a consequence, "to sell digital ICs, semiconductor houses in the 1960s and early 1970s had to provide computer equipment makers with a

Table 1

CHANGING DISTRIBUTION OF INTEGRATED CIRCUIT DEVICES IN U.S. MARKETS

U.S. Markets for ICs by End Use	Percent of Value of Total U.S. Sales of ICs				
	1962[a]	1965[b]	1969[b]	1974[b]	1978[c]
Government	100%	55%	36%	20%	10%
Computer	0	35%	44%	36%	37.5%
Industrial	0	9%	16%	30%	37.5%
Consumer	0	1%	4%	15%	15%
Total U.S. domestic shipments (millions of dollars)	4	79	413	1204	2080

[a] The figures for 1962 are derived from John Tilton, International Diffusion of Technology: The Case of Semiconductors (The Brookings Institution, Washington, D.C., 1971).

[b] The figures for 1962 and 1965 come from the U.S. Department of Commerce, A Report on the U.S. Semiconductor Industry (Washington, D.C., Government Printing Office, 1979), p. 102.

[c] These figures are rough estimates based on figures found in U.S. International Trade Commission, Competitive Factors Influencing World Trade in Integrated Circuits (U.S.I.T.C. Publication No. 1013, Washington, D.C., 1979), p. 102; Business Week, December 3, 1979, p. 68; and "1980 Semiconductor Forum," Rosen Electronics Letter (Rosen Research Inc., New York, July 14, 1980), p. 150.

complete 'kit' of electrically compatible parts that could be interconnected into a computer configuration. As a consequence, digital IC products came to be grouped into "families" such as Resistor-Transistor Logic (RTL), Diode Transistor Logic (DTL), and the durable Transistor-Transistor Logic (TTL)."[14] The early computer market was dominated by competition between these different bipolar design "families."

Table 2

KEY DIGITAL INTEGRATED CIRCUIT PRODUCT FAMILIES, 1961-1975

Project Family	Approximate Introduction Date	Originating Firm
RTL (Resistor-Transistor Logic)	1961	Fairchild
DTL (Diode-Transistor Logic)	1962	Signetics
ECL (Emittor-Coupled Logic)	1963	Motorola
TTL (Transistor-Transistor Logic)	1964	Sylvania/TI
CMOS	1968	RCA
Schottky TTL	1970	TI
1K MOS RAMs	1970	AMS/Intel
Bipolar RAMs	1972	Fairchild
4K MOS RAMs	1973	Intel/Mostek/TI
Microprocessor	1973	Intel
16K MOS RAMs	1976	Intel/Mostek

SOURCE: Charles River Associates, Inc., Innovation, Competition, and Government Policy in the Semiconductor Industry, March 1980.

The first proprietary ICs were introduced by Fairchild and Texas Instruments; Fairchild offered circuits based on Resistor Capacitor. Transistor Logic (RCTL) and Texas Instruments offered circuits based on Direct Coupled Transistor Logic (DCTL). These early product "families," while used in the Apollo guidance computer and the Minuteman II missile system, had design weaknesses and were quickly supplanted by DTL and RTL. Fairchild's 930 series DTL emerged as the industry leader in the period from 1965 to 1967. Its share of the then emerging commercial IC market, with demand from computer manufacturers the driving force, grew quickly from 18 percent in 1964 to 24 percent in 1967.[15] Texas Instruments, which had been the industry's leading producer of integrated circuits with more than 32 percent of the market in 1964, watched its market share drop almost in half by 1967 during a period in which total industry sales of integrated circuits almost doubled.[16] Innovative circuit design and aggressive price cutting enabled Fairchild to grow rapidly and lead an increasing number of IC merchant producers in the early penetration of the computer and industrial markets.

Texas Instruments soon regained its market momentum with the introduction of a family of proprietary TTL circuits whose fast-switching speeds proved to be more appealing to the computer market than Fairchild's earlier family of DTL circuits. Again, innovation in integrated circuit design, the introduction by Texas of a set of TTL chips which individually implemented complete computer functions (adders, coders, decoders, and 4-bit serial memories), and aggressive price-cutting by Texas's second source -- National Semiconductors, a recent entry in the merchant market -- enabled TTL bipolar logic family to regain a dominant position in computer hardware design by 1969. (A "second source" refers in the industry to a firm that produces a product originally introduced by someone else. Most users of components require a "second source" to assure a secure supply. The term second source refers to a specific role in the market.) Building on that base, in 1970 Texas introduced Schottky TTL, which greatly improved the speed and packing density of its earlier TTL family and sustained Texas's leadership in the merchant bipolar logic market through the early 1970s.

The success of Texas Instruments in the bipolar logic market illustrates what we have spoken of earlier as the first principle of component-system interaction: that increasingly, components are technically able to implement basic features of what previously had been regarded as an electronic system. The introduction by Texas Instruments of single chip adders, coders, decoders, and memories in the late 1960s is a classic example of the component-system relationship. By designing computer hardware subsystems on single component chips, Texas reduced the cost of these subsystems to the computer market and put itself in a dominant position in the rapidly growing computer market for digital ICs. Component manufacturers did not, however, proceed to develop a "chip version" of every electronic system and subsystem in existence, for two reasons. The first reason is that the costs of designing such chip systems are very large. The second is that in order to amortize the design costs and attain low production costs, large production runs are necessary. These large production runs are simply not possible for the many electronic system products that have small markets.

As the industry approached the era of large scale integration, these economic considerations influenced the strategic planning of IC manufacturers and came to be characterized as the "custom versus standard" debate. As neatly summarized by Charles River Associates:

> Although not universally held, the general semiconductor industry consensus in the late 1960s was that the future of digital integrated circuits lay in custom LSI. The need for standard parts was expected to be small (Electronics, 2/20/67). The principal reason LSI was expected to be dominated by custom rather than standard products was that most semiconductor experts believed that the innovating equipment maker would not want to find that the complex integrated circuits, which determined the performance of its product, were readily available to its competitors. With early bipolar logic the equipment maker could differentiate itself from competitors by cleverly interconnecting standard ICs. In a design where LSI was to be used, most of the logic needed was now packed into a few ICs and therefore much fewer produced performance differentiating options were open to the equipment manufacturer, unless the LSI used were circuits custom designed to optimize system performance.[17]

A number of strategies were developed to meet the expected demand for custom circuits. Both Texas and Fairchild planned to build wafers for inventory containing different standard logic gate designs, which could then be pulled and processed through final masking to connect the logic gates on the wafer into the customer's unique circuit requirements. Texas called its approach "Discretionary Wiring" and Fairchild called its system "Micromatrix."[18]

The custom market, however, never really emerged as conventional wisdom in the mid-1960s had anticipated. The "pull" of newly emerging mass markets in special calculator chips and semiconductor memories and the "push" of a newly developed technology -- metal oxide on silicon (MOS) -- conjoined to render the custom versus standard debate relatively moot and served to smooth the industry's entry into the era of large scale integration (LSI). Two choices then came to dominate the competitive strategies of IC manufacturers: on the one hand, LSI products were designed which implemented widely used components; on the other, LSI products were designed with sufficient flexibility that they could be used to implement a variety of system functions.

The calculator market posed the custom versus standard LSI conflict most starkly. Mostek, founded in 1969, was the first company to produce a single chip calculator, a chip which included four functions: add, subtract, multiply and divide. Intel, founded in 1969, working with the same calculator manufacturer as Mostek, was faced with the task of having to design a custom chip for a family of calculators. The key issue the company faced was whether the custom circuit could command a sufficient market both to justify the investment in design and production costs, and to get far enough down the learning curve in production to permit low prices. Intel's solution, the microprocessor, was a pioneering advance in flexible product design which gave the industry a new way out of the custom versus standard battle: by programming the on-chip memory, the microprocessor could be customized for each application.

The custom versus standard conflict, therefore, was resolved from two directions. On the one hand, what appeared to be "custom" markets rapidly proved to be mass markets for relatively low-cost MOS integrated circuits in calculators, watches, and semiconductor memories. On the other hand, the microprocessor, a standard single-chip central processing unit whose add-on memory could be programmed for customized functions, allowed integrated circuit manufacturers to break out of the vicious cycle (greater complexity leading to higher costs leading to smaller markets) and enter a wide field of new applications markets.

Between 1966 and 1972, thirty new "merchant" companies entered the U.S. integrated circuit industry. As Table 3 suggests, most of the new entrants were founded by management and technical personnel from existing companies. The mobility of technical personnel in the industry derived from two factors. First, at least until the 1969 changes in the capital gains tax, the venture capital market had been a ready source for start-up capital; and second, the domestic integrated circuit market was growing so rapidly and the number of potential product technologies becoming so diverse that none of the major merchant companies could exploit and develop the full potential of its existing technological resources. The capital constraints which rapid growth placed on company resources meant that firms often had to choose between expanding capacity and developing new products. There can be little doubt that frustration with the pace of product development as well as a market growth environment favoring entrepreuneurial risk contributed to the number of new entrants which emerged during the period.

By the early 1970s as a result of the wave of new entrants was creating a highly competitive industry structure. One indication of this was that in 1965 the four largest merchant firms accounted for 69 percent of the industry's total shipments, but by 1972 their share had dropped to 53 percent. Likewise, the

Table 3

U.S. SEMICONDUCTOR COMPANIES FOUNDED BETWEEN 1966 and 1976

Company name, date founded	City	Previous employment of founders, no. of founders
American Microsystems (1966)	Cupertino	Philco-Ford (4)
National Semiconductor	Santa Clara	Fairchild (3)
Electronic Arrays (1967)	Mt. View	Philco-Ford (4), Bunker-Ramo (2)
Intersil (1968)	Sunnyvale	Union Carbide (3)
Avantek (1968)	Santa Clara	Applied Technology (4)
Integrated Systems Technology (1968)		Philco-Ford (3)
Nortec Electronics Corp. (1968)	Santa Clara	Philco-Ford (2)
Intel (1968)	"	Fairchild (3)
Precision Monolithic (1969)	"	"
Computer Microtechnology (1968)		"
Qualidyne (1968)	Sunnyvale	Intersil (1), Fairchild (2), Leher (1)
Advanced Memory Systems (1968)	"	Fairchild (1), IBM (2), Motorola (1), Collins (1)
Communications Transistor Corp. (1969)	San Carlos	National Semicoductor (3)
Monolithic Memories (1969)	Santa Clara	IBM (1)
Advanced LSI Systems (1969)		Nortec (1)
Mostek (1969)	Carrollton, TX	TI
Signetics Memory Systems (1969)	Sunnyvale	Signetics (2), IBM (2), HP (1)
Advanced Micro Devices (1969)	"	Fairchild (8)
Four Phase (1969)	Cupertino	Fairchild (6), General Instruments (2), Mellonics (1), other (1)
Litronix (1970)	"	Monsanto (1)
Integrated Electronics (1970)	Mountain View	Fairchild (2)

Varadyne (1970)		
Caltex (1971)		TI (2), Nortec (4)
Exar (1971)	Sunnyvale	Signetics (3)
Micropower (1971)	Santa Clara	Intersil (2)
Standard Microsystems (1971)	Hauppauge, NY	Four Phase (1), Electro-Nuclear Labs (1), Nitron (1)
Antex (1971)		
LSI Systems (1972)		
Nitron (1972)	Cupertino	
Frontier (1972)	Newport Bch	Caltex (1)
Spectronics (1969)	Richardson, TX	TI
Interdesign (1972)	Sunnyvale	Signetics (1)
Synertek (1974)	Santa Clara	CMI (3), AMI (4), Fairchild (1)
Zilog (1974)	Cupertino	Intel (2)
Maruman (1975)	Sunnyvale	National Semiconductor (2)
Supertex (1976)	"	Fairchild (1)

SOURCE: U.S. Senate, Committee on Commerce, Science, and Transportation, Industrial Technology (Washington, D.C., Government Printing Office, 1978), p. 91.

largest eight firms in 1965 accounted for 91 percent of the total, but by 1972 their share had dropped dramatically to 67 percent.[19] Another indication was increased price competition across the merchant sectors as a whole: "From 1966 through 1971, a period of rapid expansion in both output and the number of firms entering the industry, net earnings as a percent of sales declined from 5.3 percent to 2.7 percent. In each of these years, they were well below the all-manufacturing industries average. Due primarily to vigorous price competition, profits per unit of sales decreased even though sales volume increased."[20] While industrial concentration registered a decline during this period, the relative market-share positions of the leading firms also changed as consequence of new merchant entry. In 1967 the leading firms were, in descending order: Fairchild, Texas Instruments, Motorola, Signetics, Sylvania, RCA, and Westinghouse. By 1973, the entire order had been reshuffled with Texas Instruments regaining its early leadership followed by Motorola, National Semiconductor, Fairchild, Signetics, Intel, American Microsystems, and Mostek.[21] Since 1973, the fast fluctuation of competitive position has continued: in 1980 Texas Instruments and Motorola remained the number one and number two producers, Intel had moved to the number three spot.

III. The Era of Large-Scale Integration: Strategy and Structure, 1972-1978

The third stage of the industry's development rested upon a succession of technological advances which allowed ever greater numbers of transistors to be built into a single silicon chip. The generic technology -- metal oxide on silicon (MOS) -- proved to have technical advantages, in terms of both production cost and density, over the bipolar techniques which had dominated early IC design and fabrication. Bipolar devices offered enhanced speed of circuit operation, but the fewer masking steps and higher yields associated with MOS design and fabrication offered the advantage of lower cost per electronic function. Thus, in tandem with enhanced circuit complexity, MOS facilitated progressive reductions in the cost of complex electronic functions, and thereby opened new growth opportunities in old and new markets.

As we noted earlier, between 1966 and 1972 thirty new companies had entered the U.S. integrated circuit industry. These new companies made their entry on the back of MOS technology. By 1973 approximately 85 percent of the sales of these newly established IC firms were concentrated in MOS technology, whereas among those firms established before 1966 only 35 percent of sales were in MOS devices.[22] Spurred by its use in hand-held calculators, digital watches, and computer main memory, sales of MOS IC products rapidly expanded between 1970 and 1975. Sales of digital MOS integrated circuits in 1970 were only some $45 million; by 1975, however, MOS sales had reached $428 million and had surpassed the total value of digital bipolar IC sales.[23] Having risked all on the development of MOS circuits, the second generation of merchant producers both developed and profited from the rapid expansion of market demand that followed the diffusion of MOS technology. The surge in market demand for MOS circuits came largely from three market segments: consumer products, computer main memory devices, and microprocessors.

Between 1969 and 1974 the consumer products market for digital integrated circuits grew rapidly. From approximately $30 million in 1969, sales of integrated circuits in the consumer product market grew to over $300 million by 1975, the bulk of which was constituted by sales of special chips for calculators and watches. The consumer market's share of total integrated circuit production rose from a mere 4 percent in 1969 to over 15 percent in 1974.[24] During this time more than a dozen of the U.S. merchant firms founded in the period between 1966 and 1972 decided to integrate forward into the marketing and sale of their own calculators and watches for the consumer market. The moves into final consumer product markets had three primary rationales: (1) sales of consumer products would presumably allow the merchant IC producers to partially insulate themselves from the cyclical swings in the component market; (2) the consumer market offered the potential of a new mass market for integrated circuits; and (3) by integrating forward, the merchant firm would capture the higher margins available to system producers. Of these rationales, only the second was substantiated in the marketplace: the consumer market did prove to be a mass market for special calculator and watch ICs, but intense price competition and the vagaries of consumer product marketing forced many of the merchant firms to abandon their consumer product lines by 1977.[25]

The use of the new MOS circuits in computer main memories spawned the growth of a new mass market for integrated circuit devices. Between 1971 and 1979 the U.S. market for digital semiconductor memories grew at an extraordinary pace: from a base of $60 million in 1971, sales of semiconductor memories were over $500 million in 1976 and reached $1.290 billion in 1979.[26] The first major breakthrough was the introduction of the 1,000 bit random access memory (1K RAM) by Intel in 1970. The rapid sales growth in RAM devices since then has been a function of increasing memory device densities and decreasing chip costs. First, storage capacity per integrated circuit advanced from 1K in 1970 to 4K in 1973 to 16K in 1976 to 64K in 1979. Second, the price per bit of storage has fallen from about 1 cent per bit in 1970 to .05 in 1979.[27] Progressive increases in storage density per chip have lead the industry into the "virtuous cycle" of increased production volume leading to lower cost per bit leading to further increases in production volume. This cycle has come to be known as the "learning curve": for each doubling of cumulative output, the cost per electronic function has declined on the average by 28 percent. With the cost per electronic function declining at such a rapid and regular pace, there has been strong economic stimulus underwriting the rapid growth of memory device sales. But we must not forget that competition among the merchant producers on both circuit price and performance was the driving force behind the rapid diffusion of MOS-based circuits in the computer memory market.

Finally, the introduction of the microprocessor by Intel in 1971 offered "as big a step forward in digital systems as did the original integrated circuit."[28] The microprocessor launched "a virtual revolution" in the application of microelectronics to a variety of products and processes.[29] In essence, a microprocessor is a single-chip version of a computer's central processing unit. But its flexibility, a consequence of its capacity to be programmed for a variety of applications, introduced a new set of marketing challenges and strategic choices into the dynamic of market competition and product development. The fact that the specifics of the microprocessor's operation could be customized in its programmable memory meant that it could be tailored to a variety of user's specific requirements. However, while the relatively low-cost "intelligence" embodied in microprocessor hardware encouraged diffusion into new applications markets, the cost of developing application programs or instruction sets for specific applications emerged as the new barrier to penetration and development of those applications markets.[30]

Competition between merchant producers of microprocessors, nevertheless, has rapidly brought the hardware cost of the device down and led to successive generations of increasingly sophisticated 4-bit, 8-bit, 16-bit, and, recently, 32-bit devices.[31] But of equal significance has been the shift in market strategies that has characterized the competition. Two general directions can be identified. First, in order to expand and penetrate the new applications markets which the relatively low cost of microprocessor hardware had made possible, a number of the merchant firms have established "learning centers" and offered "development systems" which allow the microprocessor user to program in high level computer language an instruction set for his specific application. Second, in order to capture the higher value-added associated with the microprocessor, a number of merchant firms have integrated forward into the microcomputer and minicomputer markets, and one has moved into the plug-compatible mainframe market. Both strategies imply that microprocessor manufacturers have increasingly taken on the appearance and characteristics of systems-product houses in order to maximize sales of their new systems products. By 1977, sales of peripheral and input-output devices exceeded sales of the microprocessor itself, and the market for memory chips associated with the use of the microprocessor -- RAM, ROM, p/ROM, and Ep/ROM -- was twice the value of microprocessor sales.[32] The total value of the market for the microprocessor and its family of peripheral and memory devices has grown rapidly from $25 million in sales in 1974 to over $550 million in sales in 1979.[33]

In effect, the introduction and development of the microprocessor altered both merchant firm strategies and the structure of the merchant market. The microprocessor, along with semiconductor memory devices, has proved to be, in essence, a third generation -- following mainframes and minicomputers -- of computer technology. Each generation has been fathered by advances in semiconductor technology, and each has had the effect of further diffusing computational power throughout society. The uniqueness of the microprocessor for the merchant firm lay in the fact that it was more of a "systems" product than any component the merchant sectors had produced before. Though both mainframe and minicomputer manufacturers have made ample use of the device in their own systems (to enhance both performance and cost), the microprocessor provided the foundation upon which merchant firms began gradually to evolve into marketing vehicles for the third wave of diffusion of computer technology.

Finan's comment that the current phase of the U.S. industry's growth may be characterized as "the marketing era" gains new significance in this context.[34] As manufacturers of a complex, system-like component, the merchant firms have faced the primary strategic task of penetrating those markets in which electronic "intelligence" had yet to be applied because its cost had been prohibitive. Unlike the case with the previous generation of intelligent machines -- the computer and minicomputer -- the application of the microprocessor to new products and process equipment was not limited by size, complexity, or power consumption. Moreover, in the 1970s, as competititon in the microprocessor field began to accelerate, prices began to fall rapidly; by 1980 standard 8-bit single-chip microcomputers (a microprocessor chip that incorporates a main control program in ROM, a clock oscillater, some input-output capability and some RAM capacity) were selling in the $8 to $5 range. Thus, hardware cost rapidly became marginal in a whole variety of application fields, and applications software emerged as the major barrier to diffusion and as a major marketing challenge to the merchant firms.

In the early 1970s the least expensive way of solving a problem which required software flexibility was to use a minicomputer. This solution was too expensive for many problems. The introduction of the microprocessor, however, changed this radically. For a few hundred dollars digital hardware could be purchased which was powerful enough to solve many problems and which was software programmable. Although the cost of microcomputer hardware decreased, the cost of developing the software necessary to the application often increased. This increase in software costs is attributable to the increasing complexity of applications software and a general increase in the cost of software development.

Software is generally of three types.[35] Systems software is the means by which a computer is given coordination. It includes such packages as compilers and operating systems. It is very costly to write, but once written can be used for any application. Software tools include editors, debuggers, and other programs likely to be of general use to the programmer writing applications software. Software tools, like systems software, can be used for any application. Applications software consumes well over two-thirds of all programming resources. Typically, applications software is written in a high-level language such as COBOl in order to reduce the number of man-hours necessary to develop a specific application.

Early microprocessors forced programmers to program in the lowest of computer languages, machine language. For very short, simple programs this presented no problem, but as applications expanded so did the length of the programs, causing software development costs to soar. A partial solution was the introduction of microprocessor development systems. These systems provided programmers with software tools, but they did not yet allow the programmer to program in a high-level language.

The advent of the 16-bit microcomputer exacerbated the situation. A software application for a 16-bit microcomputer now costs more than 5 million dollars and accounts for 50 to 90 percent of total design cost, depending on the application. The IC manufacturers reacted to this problem in two ways: by providing most 16-bit microcomputers with facilities for high-level language, like PASCAL, and by implementing in hardware operations that had previously been done in software. This mix of hardware and software to yield "firmware" or standard applications "solid state software" has helped the microprocessor firms solve some of the more basic marketing challenges of their new product, and it has brought them, through hardware, into a rapidly growing new market for standard software. Most important, however, it has transformed the leading IC firms from simple component houses into the latest generation of computer systems companies.

To summarize, large-scale integration implied that the integrated circuit was able to implement on a single chip what previously would have been regarded as an entire electronic system. As a flexible or programmable device, the microprocessor is only the most pervasive example of this characteristic feature of LSI products. The change in product complexity, however, was accompanied by a change in firm strategies, as many of the "merchants" began to follow the complexity of their system-like products into the final products in which they were used. From the calculator market to the microcomputer market, the leading U.S. "merchant" firms -- Texas Instruments, Fairchild, Intel, National Semiconductor, Motorola -- are developing into the next generation of diversified electronic system manufacturers, while the next tier of "merchants" find secure niches in those markets which others will most likely dominate.

As integrated circuit components gradually took on the character of complete electronic systems during the evolution of large-scale integrated circuit design, the strategic importance of integrated circuit design capability to final electronic system producers, both in the United States and abroad, became more acute. As a consequence, during the period 1972-1979, systems producers began to integrate backwards into integrated circuit design and production, either by creating their own IC capacity or by acquiring existing merchant producers. As Table 4 shows, since 1975 at least fourteen independent merchant houses, including

Table 4

CORPORATE INVESTMENTS IN U.S. SEMICONDUCTOR COMPANIES

U.S. Semiconductor Company	Corporate Investor	Percent Ownership[a]	National Base
Advanced Micro Devices	Siemens	(20%)	West Germany
American Microsystems	Robert Bosch	(12.5%)	West Germany
	Borg Warner	(12.5%)	United States
Analog Devices	Standard Oil of Indiana		United States
Electronic Arrays	Nippon Electric		Japan
Exar	Toyo	(53%)	Japan
Fairchild Camera	Schlumberger		Netherlands Antilles
Frontier	Commodore International		Bahamas
Inmos	National Enterprise Board		United Kingdom
Interdesign	Ferranti		United Kingdom
Intersil	Northern Telecom	(24%)	Canada
Litronix	Siemens		West Germany
Maruman IC	Toshiba[b]		Japan
Micropower Systems	Seiko		Japan
Monolithic Memories	Northern Telecom	(12.4%)	Canada
MOS Technology	Commodore International		Bahamas
Mostek	United Technologies		United States
Precision Monolithics	Bourns		United States
SEMI, Inc.	General Tel. & Elec.		United States
Semtech	Signal Companies		United States
Signetics	Philips	(merger)	Netherlands

Siliconix	Electronic Engr. of Calif.		United States
	Lucas Industries	(24%)	United Kingdom
Solid State Scientific	VDO Adolf Schindling	(25%)	West Germany
Spectronics	Honeywell		United States
Supertex	Investment Group		Hong Kong
Synertek	Honeywell		United States
Unitrode	Signal Companies		United States
Western Digital	Emerson Electric		United States
Zilog	Exxon		United States

SOURCES: Morgan Stanley Electronics Letter, December 31, 1979.
Dataquest, Inc., January 1979, for percent of ownership.
The consulting group BA Asia Ltd., 1980 for Maruman IC data.

[a] No percentage indicates 100 percent (wholly owned), or presumed to be wholly owned, in the absence of data.

[b] Purchased in 1980 from Mansei KK, pending litigation.

Fairchild and Signetics, have been acquired by foreign companies (see Table 4). With the notable exception of Fairchild, many of these merchant companies welcomed acquisition as a means of financing further growth or of establishing financial solidity in a period of financial crisis. The financial constraints imposed on smaller firms by the highly competitive and rapidly growing integrated circuit market in the 1970s made acquisition by a financially more secure parent an attractive option. For, unlike the major integrated circuit manufacturers in Europe and Japan, which by virtue of both vertical integration and a domestic market environment in which high debt to equity ratios are commonplace, merchant firms in the United States depend primarily on equity and internally generated funds to finance growth. Given the vicissitudes of the equity market and periodic downturns in the semiconductor business cycle, acquisition proved to be a viable avenue through which to finance a position in a market characterized by rapid growth and rapid technological change.

While foreign companies played a dominant part in the wave of merchant acquisitions over the period 1975-1979, major American users of integrated circuit devices began during the 1970s to set up captive IC production and design facilities. Among the increasing number of American firms involved in captive production are defense equipment companies such as Hughes, minicomputer companies such as DEC, and electronic instrumentation manufacturers such as Hewlett-Packard. Overall, systems producers appear to have set up captive facilities in order to give their final systems products an important competitive edge. This competitive edge may exist because the IC is custom-tailored to meet the requirements of system features, or because the company has invested in R&D or processes to produce higher performance or reliability than is typical for merchant products. Since these characteristics are of significant value to users, the R&D investment underlying development of chips that enable such characteristics may earn a high rate of return. Such returns are a fundamental explanation of the advantages of vertical integration to systems producers.

IV. The International Character of the American Industry, 1970-1980

The United States integrated circuit industry is composed of firms which are multinational in their operations. Direct foreign investment by U.S. merchant firms has been an integral aspect of their penetration of foreign markets and of their competitive position in the world market. Foreign investment has been primarily of two types: investment in offshore assembly facilities, and point-of-sale affiliates.[36] Offshore assembly affiliates have been established largely in Southeast Asia and Latin America to take advantage of low-cost foreign labor to assemble U.S. manufactured subassemblies for export back to the United States and to third markets. Point-of-sale affiliates, on the other hand, have been established primarily in Europe both to mitigate the impact of the relatively high European Economic Community tariff and to better coordinate integrated circuit designs with European buyer demands.

The shift to offshore assembly by U.S. integrated circuit firms during the period 1964-1972 was primarily an aggressive move by which to reduce labor costs in the most labor-intensive stages of integrated circuit manufacture. It began with Fairchild's opening in Hong Kong. The natural division in integrated circuit production between wafer fabrication, assembly, and testing allows the assembly stage of production to be located at a different facility from the fabrication and testing stages without any significant impact on learning economies. In turn, the substantial difference between wage costs in Southeast Asian developing countries and the United States offers a substantial economic incentive to shift assembly offshore. Finan estimates that the lower wage rates available in Southeast Asia and Latin America could yield up to a 50 percent decline in total IC manufacturing costs. "For example, the total manufacturing cost for an MOS integrated circuit in 1973 was approximately $1.45 per device with assembly done in Singapore. If the same device was assembled in the U.S., the total manufacturing cost would be about $3.00."[37]

The timing and location of offshore assembly investment, however, suggests an additional set of economic incentives. On the one hand, the Tariff Schedules of the United States were amended in 1963; under items 806.30 and 807.00, imported articles asembled in whole or in part of U.S. fabricated components became dutiable only to the extent of the value added abroad. "Reductions in the duties achieved through use of Items 806.30 and 807 act to offset the transportation expenses incurred in using offshore facilities," thereby enhancing the final cost competitiveness of U.S. firm imports into the United States against foreign imports which do not receive similar tariff treatment.[38] On the other hand, beginning in 1967, the governments of Mexico, Taiwan, Singapore, Malaysia, and Korea established "export platforms" to encourage direct foreign investment in manufacturing for export. While the packages of economic incentives differ among developing countries, most involve duty-free export and import, property tax reductions, and some form of income tax holiday. While far from determinative, these various inducements were found in at least one survey to have ranked second behind the availability of low-cost labor among the reasons cited by industry executives for the shift to offshore production.[39]

The first great wave of offshore assembly affiliates was established during that period with Mexico, Hong Kong, Malaysia, Singapore and Korea the leading offshore locations.[40] By 1974, the number of offshore assembly facilities in low-wage developing countries had risen to 69.[41] By 1978, the top nine U.S. integrated circuit manufacturers together had 35 offshore assembly facilities in 10 developing countries in Southeast Asia and Latin America. [42]

The second type of direct foreign investment has been the establishment of point-of-sale affiliates, primarily in Europe, to enhance the ability of U.S. firms to penetrate the foreign market for integrated circuits. Finan lists five general functions which influenced the decision by U.S. firms to initiate assembly in the European market: (1) the size of the European market; (2) the relatively high European Economic Community tariff (17 percent of value); (3) the competitive advantage over other U.S. firms which early investors, such as Texas Instruments, had derived from their European operations; (4) British and French government pressure on U.S. firms, particularly those serving the European military market, to take on more of the character of domestic producers; and (5) the fact that, as integrated circuit devices began to implement entire systems on a single chip, greater coordination in chip design between buyer and seller became a crucial factor influencing sales.[43]

The major period of direct foreign investment by U.S. integrated circuit firms in Europe occurred between 1969 and 1974. By 1974, U.S. firms had established over 46 point-of-sale affiliates within the European Economic Community, of which at least 18 were engaged in complete manufacturing activities.[44] The early U.S. leaders in integrated circuit technology -- Texas Instruments, Fairchild, and Motorola -- also led the move to European direct investment. However, with the softening of IC demand in the United States during the recession of 1979-1980, the more aggressive of the post-1966 companies also moved to capture sales volume in Europe, where demand for integrated circuits was still strong.

The same factors which led U.S. firms to invest in point-of-sale affiliates in Europe also encouraged U.S. firms to invest in Japan, though with much less success. Only Texas Instruments with its strong patent position was able to extract from the Japanese government permission to establish a wholly owned manufacturing subsidiary in Japan in the period prior to 1978.[45] To circumvent the Japanese 12 percent ad valorem tariff on imports of integrated circuits from the U.S., Finan suggests that other U.S. firms in the period prior to 1974 used offshore assembly affiliates in the developing countries of Southeast Asia as export platforms to the Japanese market. Imports into Japan from an affiliate located in a less developed country were duty-free.[46] However, prior to 1975, integrated circuits which contained more than 200 circuit elements could not enter Japan, from any point of origin, without the permission of the Japanese government.[47] As a consequence, U.S. firms had relatively little success in translating their superior technological capabilities and production experience into a strong position in the Japanese market. Whereas in 1975 U.S. firms held 98 percent of the U.S. market for integrated circuits and 78 percent of the Western European market, their share of the Japanese market for monolithic ICs was a mere 20 percent. The Japanese "liberalization" that began in 1976, while eliminating the import quota system on advanced ICs, left the 12 percent ad valorem tariff in place. Moreover, though the evidence is scanty, it appears that, at about the same time, Japanese customs officials began, for tariff purposes, to treat imports from U.S. affiliates in less developed countries as coming directly from the United States if more than 50 percent of an item's value-added originated in the United States.[48] Obviously, this nullified the tariff advantages to U.S. firms of exporting to Japan from Southeast Asian assembly affiliates.

This political structure governing market access and trade in integrated circuits has therefore influenced the pattern of exchange in which U.S. firms have engaged. In order to exploit their lead in IC technology and production experience, U.S. firms have been compelled by tariffs to invest in point-of-sale affiliates in Europe; and a variety of trade restrictions in Japan (investment controls, quotas, and tariffs) have led them to license their technology to Japanese firms as a means of generating residual earnings in a market to which access has been at best difficult. The implication of these technology transfers for the continued international competitiveness of U.S. firms will be considered in greater detail in Chapter Three. For the moment, it is important to recognize the manner in which the political structure of international trade shapes the type of exchanges in which firms engage across national boundaries.

In order to generate residual earnings in the relatively "closed" Japanese market, U.S.-based firms have licensed technology to Japanese firms. There are two basic types of license: (1) a patent license, in which the licensee is given the right to use specific patents of the licenses; and (2) a second source or know-how license, in which the licensee in addition to receiving the legal right to use patents of the licenser also receives some form of technical assistance in putting the patent into production. Given the strong patent positions of U.S.-based firms -- a product of their leadership in technological innovation -- and the relative backwardness of Japanese technology, particularly in digital bipolar and MOS technologies, licensing arrangements have generated considerable returns to U.S. firms. Annual Japanese patent royalty payments between 1964 and 1970 for semiconductor and integrated circuit licenses went from 2.6 million dollars to over 25 million dollars in 1970.[49] As the Japanese shifted their IC production mix toward digital MOS integrated circuits in the mid-1970s, royalty payments to U.S. firms for integrated circuit technology alone have begun to exceed 20 million dollars per year, or almost 2 percent of the value of Japanese integrated circuit production.[50] Not all licensing agreements involve royalty payments, however. Indeed the most characteristic form of technology transfer is the "cross-license" in which patents or know-how are exchanged. Nonetheless, where royalty payments are involved, it appears that payments from Japanese firms constitute the bulk of foreign receipts by U.S. firms. The fact that the Japanese market remains the only major world market which U.S. firms have failed to penetrate in any significant way seems to have enhanced technology licensing as a means of generating some modest residual return from the Japanese market.

By 1971 virtually every U.S. semiconductor firm had at least one offshore assembly affiliate. This international location of the U.S. industry has fundamentally influenced both the <u>composition</u> and the <u>level</u> of U.S. exports and imports. According to statistics compiled by the U.S. Department of Commerce, the last year in which the United States ran a trade surplus in integrated circuits was 1970.[51] Beginning in 1971, the Commerce statistics indicate that the U.S. trade deficit grew steadily from 3 million dollars to 672 million dollars in 1977.[51]

Measuring the U.S. trade balance in terms of <u>finished integrated circuits</u>, however, obscures the real strengths of the U.S. integrated circuit industry and the significance of its international offshore assembly activities. In this respect, both the International Trade Commission study and the recent report of the Commerce Department are flawed. Throughout the 1970s the largest single category of U.S. semiconductor exports has been semiconductor "parts and accessories." This category is primarily composed of chips, dice, and wafers destined for U.S. offshore assembly facilities in Europe, Latin America, and Southeast Asia which, when assembled and tested, become "integrated circuits."[52] While exports of finished integrated circuits from the United States were only some 348 million dollars by value in 1977, exports of chips, dice, and wafers were over 958 million dollars in 1977. In turn, U.S. imports of finished integrated circuits amounted to some 1.020 billion dollars in 1977. Imports of chips, dice and wafers amounted, however, only to some 60 million dollars.[53] Thus, before adjusting for 806-807 imports, the U.S. trade balance in finished integrated circuits and chips, dice, and wafers shows in fact a surplus of 126 million dollars. Adjusting U.S. total imports in 1977 for imports entered under TSUS items 806.30 and 807 helps clarify the pattern of trade and the international division of labor by which U.S. firms serve both their domestic and foreign market positions. Of the 958 million dollars of chips, dice, and wafers that the U.S. exported in 1977, some 513 million dollars worth were re-imported back to the United States under TSUS items 806.30 and 807 after having been assembled by U.S. offshore affiliates primarily in Malaysia, Singapore, Hong Kong, and the Philippines. The remaining 445 million dollars worth of dice, chips, and wafers shipped to and assembled by U.S. offshore assembly affiliates appear to serve U.S. firms in their foreign markets.

The pattern of trade described by these figures suggests the following conclusions. First, most U.S. exports of finished integrated circuits serve four markets: Britain, France, West Germany, and Japan. Second, U.S. exports of unfinished ICs (chips, dice, and wafers) go primarily to five countries: Malaysia, Singapore, Hong Kong, Korea, and the Philippines for final assembly and packaging by U.S. affiliates located there. Third, the re-export of finished integrated circuits out of Malaysia, Singapore, Hong Kong, Korea, and the Philippines primarily serves five markets: the United States, Great Britain, France, West Germany, and Japan. Thus, U.S.-based integrated circuit manufacturers maximize both scale economics and learning-curve efficiencies on wafer fabrication operations in the United States, and they minimize labor costs by assembling finished integrated circuits primarily in Latin American and Southeast Asia for export and final sale to the five major industrial nations.

In terms of the international division of labor characteristic of the organization of production by U.S. firms, it seems that no less than 80 percent of all U.S.-based wafer fabrication operations is done in the United States. Wafer fabrication is both the most technically difficult and the highest value-added stage of integrated circuit production. Of the remaining 20 percent, it seems reasonable to assume that most, if not all, of it occurs under the auspices of U.S. manufacturing affiliates in Europe and Japan. The situation for assembly operations appears to be just the reverse: it is likely that no more than 20 percent of total assembly operations occurs in the United States and that 80 percent of it is conducted under the auspices of U.S. affiliates in Latin America, Southeast Asia, and to a much lesser extent in Europe. Assembly is both the most labor-intensive stage of production and the lowest value-added stage. It should be noted, however, that more stringent quality requirements and an increasing level of automation in assembly and packaging operations seem, in the current competitive environment, to imply a trend back toward assembly in the United States. Nonetheless, the existing international division of labor characteristic of U.S.-based integrated circuit producers, while taking labor-intensive assembly operations offshore, has left concentrated in the United States the highest value-added stage of production -- wafer fabrication -- and the highest skilled labor phases of production-research and development and fabrication. This organization of production is therefore advantageous to both U.S.-based firms and to the U.S. domestic economy. A brief review of the pattern of growth and investment by the U.S. integrated circuit industry over the period 1974-1978 will further clarify this point.

Between 1974 and 1978, U.S.-based shipments of integrated circuits grew at an annual rate of 17.7 percent from $1.056 billion in 1974 to $3.950 billion in 1978. If we exclude the recession of 1975, the annual growth rate over the period 1976-1979 is even more dramatic: shipments in 1976 were some $2.5 billion and by 1979 exceeded 5.0 billion -- an annual average growth rate of 26 percent.[54] Investment in production equipment worldwide was over $355 million in 1974 and exceeded $662 million by 1978, with more than 75 percent of that investment being made in the United States.[55] Investment in plant and plant improvements was over $188 million in 1974 and exceeded $234 million in 1978, with more than 71 percent of that investment being made in the United States.[56] Expenditures in IC research and development by U.S. firms were $329 million in 1974 and exceeded $529 million in 1978.[57] While little detailed information is available, it appears relatively certain that no more than 10 percent of these R&D sums was invested outside the United States.

To put things in some perspective, industry sources suggest that more than half of total integrated circuit research and development by U.S.-based firms is done under the auspices of IBM and ATT. Together, then, these two firms appear to have invested more in integrated circuit R&D in 1978 than the entire Japanese IC industry combined. In turn, while Japanese integrated circuit production has grown rapidly, at an annual average rate of 30 percent between 1974 and 1978, it has been expanding from a much smaller base. In 1978, Japanese IC shipments still had not exceeded 30 percent of the value of total U.S. shipments of ICs.

V. Summary

This chapter has sought to outline the stages of the U.S. integrated circuit industry's development in terms of the shifting composition of the markets the industry has served and the changed character of the products it has produced. In the earliest period, from the invention of transistors through the commercial introduction of the integrated circuit, the U.S. military played the role of "creative first user." Military R&D programs, emphasizing miniaturization, high performance, and reliability set the direction for early product design, and military and space agency procurement provided an initial market for the integrated circuit. The existence of strong government demand contributed to the entry of new firms and accelerated the pace of diffusion of the integrated circuit into non-military markets.

The second stage of the industry's development rested upon its synergistic relationship to the computer and telecommunications industries. Advanced integrated circuit design moved from the implementation of basic logic circuits to the implementation of entire computer subsystems on a single chip of silicon. In turn, the growth of the mainframe and minicomputer markets was both fueled by and contributed to the rapid expansion of domestic digital integrated circuit production.

The third stage of the industry's development rested upon the shift to MOS technology, the emergence of large-scale integrated circuit designs, and the appearance of the microprocessor. This stage saw a wave of new merchant entries and a broadening of the final systems markets that the integrated circuit producer served. Large-scale integration brought with it new markets in semiconductor memories, in consumer products, in telecommunications, and most importantly in a wide variety of applications markets for the microprocessor and microcomputer. In turn, the strategies of firms changed as the markets for the more complex LSI ICs became more segmented, and as the microprocessor, the third generation of computation equipment, offered new market development opportunities and challenges.

As the industry has moved through large-scale integration, the nature of the products it produces has changed and therefore so has its status as a "components" industry. Increasingly, the major merchant firms in the industry appear to be consolidating their strengths in integrated circuit technology and emerging as a new generation of diversified electronics "systems" manufacturers. In turn, the smaller merchant firms are increasingly establishing themselves within niches of the rapidly segmenting markets for integrated circuit components. Also, "captive" production -- either through acquisition or in-house start-ups -- appears to have steadily increased as a variety of final electronic systems producers have recognized the strategic nature of the integrated circuit to their future product development and market growth.

Although the industry's evolution has certainly been shaped by changes and by growth in the final product markets for semiconductor devices, it is important to recognize that these market opportunities were a direct result of successive innovations in semiconductor technology. In the early years, semiconductors were simply replacements for vacuum tubes: they performed the same functions more effectively, but they did not fundamentally change the products into which they were incorporated. In the second stage of the industry's development, advances in semiconductor technology made possible the substitution of electronic circuits for many types of electrical mechanical functions. In the third phase of the industry's development, the advent of the microprocessor opened up new market opportunities beyond those substitution uses for which semiconductor technologies had proven cost-effective and performance-enhancing. In essence, the microprocessor and the growing range of complex large-scale integrated circuits opened the development phase of the industry.

The character of the current U.S. semiconductor industry remains diverse and dynamic. The existence of a set of merchant firms whose primary business is the design, manufacture, and open-market sale of advanced integrated circuit devices has over time been complemented by the emergence of a rapidly increasing number of systems firms engaged in custom IC fabrication and design. Together, with the addition of the two giants of the domestic electronics industry -- IBM and ATT -- the structure of the domestic sector exhibits a technological breadth and dynamism unique in the world community. As we have argued, the existence of the merchant segment of the industry has been the critical stimulus to commercial market diffusion of integrated circuits: by making the most advanced integrated circuits available at low cost on the open market, merchants have lowered technological and capital barriers to entry in existing electronic systems markets and led the development of new markets for the application of microelectronics technology. This competitive dynamism has spurred technological advance and until recently has sustained the international competitiveness of the American electronics industry as a whole.

Chapter Two

JAPAN: MARKET POWER AND GOVERNMENT PROMOTION

On July 15, 1975, the Ministry of International Trade and Industry (MITI) and Japan's public telecommunications monopoly (NTT) agreed to unite parts of their separate, on-going LSI development research projects into a joint program aimed at the development of very large-scale integration technology (VLSI). The four-year project began in 1976 and was funded at some $250-350 million (72 billion yen). The funding was by public subsidies through MITI and NTT of some $150 million (30 billion yen), and by contributions from the program's private company participants, five of the six largest Japanese IC producers.[1]

Perhaps a quarter to a third of the project's funding was spent in the United States to purchase the most advanced semiconductor manufacturing and test equipment from U.S. equipment manufacturers.[2] These purchases inferentially support what U.S. industry observers looking at the VLSI program have suggested: that a significant part of the VLSI program was aimed at catching up to U.S. industry production capability in advanced integrated circuits. The program thus provided an assured direction and subsidy to the Japanese industry for development of process technology and advanced R&D. It thereby freed Japanese firms to apply resources to the development of advanced, high value-added ICs, aimed at the competitive penetration of the U.S. merchant semiconductor market.

The latter strategy had, in fact, coalesced with the domestic reorganization in 1971 of the Japanese semiconductor-computer-telecommunications industry.[3] From the mid-1970s on, the major Japanese firms expanded their semiconductor production capacity to meet growing demand in the variety of their domestic end-markets. The firms moved gradually from a semiconductor capability significantly slanted toward more mature, less complex devices for consumer electronic products, to an advanced integrated circuit capability which could serve domestic computer and telecommunications demand.

Also from the mid-1970s on, the major Japanese semiconductor firms developed a solid marketing and distribution base in the United States -- the essential requirement for penetration of a U.S. market completely dominated by U.S. firms. After 1977, demand in the United States for 16K RAMs greatly exceeded supply. Excess demand meshed perfectly with the Japanese strategy for penetration. By the end of 1979, Japanese firms -- led by NEC, Hitachi, and Fujitsu -- had captured over 40 percent of the U.S. market for 16K RAMs. Simultaneously, the Japanese VLSI project wound down with an output of 600-700 patents, and left the participating Japanese firms seemingly well aimed toward VLSI capability. At the start of the new decade, then, the once unchallengable U.S. domination of the world integrated circuit market seemed to be in some doubt.

The VLSI program and Japanese penetration of the U.S. integrated circuit market are part of a conscious national strategy of establishing comparative advantage in the technology-intensive and knowledge-intensive industries. MITI has been explicit about its goal: "(The) spirit of basing national development on technology should be our aim in the 1980s. . . .The basic course of knowledge intensification during the 1980s should be to increase the value added of products through technology intensification. . . .International specialization between Japan and advanced countries will also become possible as a result of the growth of industries where Japan has unique, creative technologies. . . .Possession of her own technology will help Japan to maintain and develop her industries' international superiority and to form a foundation for the long-term development of the economy and society."[4]

The emergence of Japanese competitiveness in world integrated circuit markets, like the more general national goal of creating comparative advantage, rests on a conscious state and industry strategy of controlling access to the domestic Japanese market, structuring the terms of domestic competition, making available stable sources of cheap capital, and using the controlled and structured domestic market as a secure base from to gain entry and competitiveness in international markets. The purposes of this chapter are to describe these systemic features that give the Japanese semiconductor-electronics industry its advantage in international competition and to detail the industry's evolution and operation since the late 1960s. The reader will note in progressing through this chapter that the structure and detail here differ markedly from that of Chapter One. The story of the Japanese semiconductor industry's development is told differently because in fact, as in available detail, it differs extensively from the U.S. industry's development.

Section I will briefly describe the distinctive strategic character of the Japanese system as it was developed after World War II, and will examine the structure of the Japanese semiconductor-electronics industry as it exists today. This section will emphasize those features of Japanese business, finance, and state policy which assist the rapid competitive growth of Japanese firms. Section II, the bulk of this chapter, traces the evolution of the Japanese semiconductor industry during the 1970s, and emphasizes the manner in which Japanese government policies altered and assisted the strategies and capacities of the domestic Japanese firms. The focus throughout the chapter will be on how domestic Japanese industrial structure, government policies and firm capacities intertwine to promote the international competitiveness of the Japanese semiconductor-electronics firms.

I. The Systemic Advantages of Domestic Structure and Market Power

In order to fully grasp the nature and strengths of the Japanese semiconductor industry, it is necessary to characterize briefly the domestic economic system within which the industry operates.

Since the end of the Second World War, the Japanese have been committed to rapid economic development as a systematic priority. "Macro-level economic growth has been the central poltical goal to which all other Japanese policies have been subordinated during the postwar period."[5] The conscious theme of policy has been to create comparative advantage in high value-added industries as an alternative to remaining dependent on the labor-intensive industries that might seem appropriate to an economy short on resources and capital. As a "resource-poor nation" dependent on the export of manufacturers to pay even today for the importation of almost 90 percent of its energy needs, over half of its food, and the greater part of its chief resources, the Japanese chose industries for domestic development that could serve to expand overseas sales.[6] The state aggressively promoted the shift out of agriculture into industry and out of low-wage into high-wage industrial sectors. Government policy served to channel resources into those industries for which there was growing domestic demand and potential economies of scale to facilitate export. The targets were machinery, metals, chemicals, and ships in the 1950s, then automobiles, heavy machinery and by the 1970s, atomic power and computers. The state played a crucial role both in manipulating the access of foreign competitors to the domestic Japanese market and in restructuring the key domestic industries to promote their export competitiveness. As we shall see in Section II, both of these tactics were an integral part of the development of the Japanese semiconductor-electronic industry.

The theory underlying both control over access and the restructuring of domestic industry was "to place undeveloped domestic industries with little competitive power under the government's active interference . . . to build up a large scale production system, while limiting entry into the domestic market of foreign enterprise with already established mass production systems and restricting the competition of foreign manufacturers in the domestic market."[7]

In the role of controlling access, the Japanese government has been characterized as an "official doorman (between domestic Japanese society and the international arena) determining what, and under what conditions, capital, technology and manufactured products enter and leave Japan."[8] Selective control over internal foreign investment discouraged foreign efforts to control Japanese firms and to manufacture in Japan. Imports were limited through tariff and non-tariff barriers to ensure that domestic firms would capture most of the explosive growth in domestic demand. Technology imports were controlled by MITI in order to force foreign firms whenever possible, to sell technology and to be content with royalty payments rather than product sales in Japan. Thus, a "closed market provided Japanese firms a stable base of demand on which to build competitive production and distribution networks."[9]

In its companion role as promoter of industry restructuring, the state followed policies "which emphasized efficiency and rationalization."[10] It encouraged competition through extensive support for expanding firms. The state organized a stable availability of cheap capital; it provided tax breaks to assure cash flow liquidity, gave R&D support, and helped to promote exports. Winners were encouraged, losers weeded out. In most sectors, a few large vertically integrated firms emerged and carved up the domestic market as a matter of company strategy and state policy. Markets were rationalized, and in MITI's words "intra-industrial specialization" was encouraged as a means of building efficient scale economies in market segments.[11] Capacity expansion was often planned with state help, and official or informal "recession cartels" were organized to manage periods of overcapacity. In these many ways, "disruptive" competition was avoided. Thus vertical integration, "rationalization, oligopolization and cartelization (were) an integral part of the sectoral development policy."[12]

Deeply contrasting images characterize the dominant analytic descriptions of the resulting Japanese economic system. At one extreme lies the image of "Japan Inc.," in which at every level of relations, businessmen and governmental promoters collaborate to further the development and international competitiveness of Japanese business. At the other extreme is "Japan the Land of Fierce Competition," in which cutthroat competition is assumed to characterize domestic Japanese markets. The available evidence in a range of economic sectors -- and as the following will show, in the semiconductor electronics sector in particular -- suggests that the extreme images are partial truths. Especially in the face of foreign economic and political power, there is a collaborative unity within the conservative coalition of business and state actors that rules Japan. Such collaboration can be expressed through formal, state-sanctioned market sharing arrangements (like the recession cartels) or through less formal arrangements among economic actors (such as the strong preference to "Buy Japanese"). Simultaneously, among members of the ruling coalition -- that is, among corporations and bureaucratic actors (such as MITI and NTT), as well as between business and the state -- there exists strong and flourishing competition. Japanese firms do compete with each other in domestic and international markets. Japanese firms disagree about strategy; they can act independently of state strategies; and they often ignore the government pressures for market rationalization to compete fiercely and directly in segments of growing markets.

In contrast to the extreme images, we would characterize the Japanese economic system as one of "controlled competition" in which the intensity of competition between firms in key industrial sectors is directed and limited both by state actions and by the formal and informal collaborative efforts of industrial and financial enterprises. It is difficult to define in a neat way where the precise limits of competitive behavior lie. Our best guess is that, as a general rule, Japanese firms within market segments tend to tolerate existing market shares while engaging in intense competition over expanding shares of growing markets. Such competition would then tend *to shade into* collaboration in the face of *foreign* penetration of domestic Japanese markets. Since outsiders will compete over existing market shares and will probably not share common Japanese goals and interests (such as national economic development), there would be a reasonable tendency among Japanese firms and the state to act in formal or informal concert against the outsider.

Thus firms compete but they also collaborate. State bureaucrats, in turn, ride with the pressures of the market. They do not administrate the market, but they do consciously contribute to the rapid growth of particular sectors. In its dual role of doorman and promoter, the state has helped in a detailed way to establish conditions of investment, risk, and collaboration that promote the long-term development and international competitiveness of favored industries. In this way, state initiative has mixed with private arrangements and domestic market competition to create extremely competitive domestic sectors. In automobiles, for example, the domestic market was closed to foreign producers, a competitive components industry was established under government leadership, and the infrastructure was laid down by public investment to permit a rapid increase in auto usage. In 1960 Japan produced 160,000 autos; by 1970, the figure was 3.1 million cars; by 1980, Japan was producing over 8 million cars a year. The consequent Japanese success in the U.S. auto market needs no recounting here. The story is similar in steel. State intervention closed the domestic market to preserve it for Japanese firms, provided cheap investment capital, staged investment through a series of rationalization plans to avoid overcapacity, and helped to manage excess capacity when it occurred. Firms did not always follow state policy, however, and by risking competitive expansion in the face of state (and sometimes industry) opposition, some firms prospered. In 1950 Japan produced about 5 million net tons of steel, by 1960 some 24 million net tons, and by 1970 over 100 million net tons per year. It was also, and remains, the lowest cost, volume steel production in the world. A full 40 percent of that production is exported every year.

Control over access on the one hand, and vertical integration, market rationalization, and oligopolization on the other hand, have thus created certain commonalities in Japanese business strategies across a range of sectors. Initial production volume is built on a tacitly closed domestic market with different firms achieving large-scale economies in part through "intra-industrial specialization" in sub-segments of each market. Intense competition between firms appears to be centered on the expanding share of the market, while existing market shares are generally tolerated. Volume production is steadily expanded through selective exploitation of market niches abroad. Those niches provide an initial penetration of foreign markets and are followed by full-scale export drives. Steadily increasing production volumes at home generate the production economies that have often made Japanese producers the low-cost international competitors. In essence, the Japanese have used a secured and controlled domestic market as the base from which to launch large scale penetration of foreign markets.

As the rest of this chapter will demonstrate, the charateristic features of Japan's high-velocity growth system, and the company strategies it encourages and sustains, have been an integral part of the development of Japan's international competitiveness in semiconductors. In pursuit of MITI's goal of creating comparative advantage in the knowledge-intensive and technology-intensive industries, the Japanese had to turn a relatively backward semiconductor industry into a world-class competitor. During the 1970s, the Japanese industry moved from a consumer product orientation and a position of relative technological inferiority in components toward a state-of-the-art capability in components, telecommunications, and computers. Before we examine that successful development in detail, let us look at what it has produced: the Japanese semiconductor-electronics industry as it looks and acts today.

Domestic Structure and Market Power

The six major Japanese producers of semiconductors are large multidivisional vertically integrated firms which manufacture electronics systems products serving end markets primarily in consumer electronics, computers, and communications. The six firms, roughly in order of their share of the domestic Japanese IC market, are NEC, Hitachi, Toshiba, Fujitsu, Mitsubishi, and Matsushita. These six firms dominate the Japanese domestic semiconductor market, and accounted for approximately 79 percent of domestic sales in 1979.[13] For these firms, the percentage of total sales in 1979 accounted for by semiconductor sales (in comparison with a sample of representative U.S. merchant firms) is as follows.[14]

Japanese Firms		U.S. Firms	
NEC	17.8%	AMD	89%
Fujitsu	6.7%	Fairchild	69%
Toshiba	5.5%	Intel	75%
Hitachi	4.1%	Mostek	93%
Mitsubishi	3.8%	Motorola	31%
Matsushita	2.3%	National	85%
		Texas Inst.	36%

These figures suggest the extent to which it is misleading to label the Japanese companies simply as semiconductor producers. Gresser's characterization of the industry as a unitary semiconductor-computer-telecommunications industry captures its systems character and the slant of its growth, but understates the industry's continued heavy involvement in consumer electronics (which consumes roughly 50 percent of ICs).[15] In order to emphasize the systems orientation of the industry, the major firms must be briefly profiled.

NEC is Japan's leading communications systems equipment producer, a strong computer manufacturer, and the largest producer of integrated circuits. It is a domestic leader in MOS LSI, and especially in memory semiconductor technology. Fujitsu is Japan's largest mainframe computer manufacturer and a leader in advanced MOS memory and digital bipolar (ECL) semiconductor production. Hitachi is Japan's largest diversified electronic systems producer serving computer, communications and consumer markets, and is a major producer of heavy industrial equipment and electrical machinery. It is strong in MOS memories and is Japan's largest producer of TTL and ECL logic circuits. Toshiba is also a large conglomerate which produces heavy electrical equipment, instrumentation, appliances and electronic systems. It is a leader in standard and custom CMOS MSI-LSI and consumer linear semiconductor devices. Mitsubishi is a large diversified producer of electronic systems, Japan's largest manufacturer of small business computers, and a manufacturer of industrial and heavy electrical machinery and appliances. It has adequate capability in MOS and digital bipolar and good capability in industrial and consumer linear devices. Matsushita is Japan's largest consumer electronics and home appliance producer. It derives most of its IC income from consumer linear ICs and is not a factor in the domestic MOS LSI and bipolar markets.[16] All of these six large firms are multi-billion dollar companies, with sales in 1979 ranging from Fujitsu's $1.8 billion to Hitachi's $10.7 billion. Most of this information is summarized in Table 5.

As the profiles suggest, and as Section II will affirm, the Japanese have rationalized the major final electronics system markets among the major domestic firms. "Intra-industrial specialization" has enabled each firm to exercise a degree of control over different product segments of the overlapping systems markets they serve. As we have seen in the general discussion of the Japanese system, such specialization characteristically enables these Japanese firms to maximize economies of scale, thereby optimizing the production cost efficiencies of their systems products. Again, this is not to suggest a lack of serious competition among some Japanese firms in major final systems products; for example, NEC and Hitachi are currently engaged in a battle for the number two spot in large-scale computers behind Fujitsu. Rather, it appears that final system markets have been rationalized, that individual firms do specialize within market segments, (Table 5, right column), but that markets are growing fast enough to permit serious competition over increasing shares in segments where the systems product strengths of the major firms overlap. Moreover, as the profiles above also suggest,

Table 5

DOMINANT FIRMS IN JAPANESE SEMICONDUCTOR (SC) INDUSTRY
(1979 sales, 1980 sales in parentheses)

Firm	Total Sales	SC Sales	SC Sales Total Sales	SC Strength	Systems Market
NEC	$3.3 bil	$590 mil	17.8%	MOS-LSI (NMOS, CMOS) Memory (16K strong, 64K redesign strong) MPU's (4-bit) Linear	Leading IC powerhouse Leader in Telcommunications Computers
Hitachi	10.7 bil	440 mil	4.1%	MOS - LSI (CMOS, NMOS) Memory (16K, 64K very Bipolar logic - ECL, Shotky-TTL MPU (Motorola)	Leading Diversified systems computers, producer in communications, consumer, heavy industrial, and electrical machinery
Fujitsi	1.8 bil	120 mil	6.7%	MOS memory (NMOS) (64K strong) Bipolar logic - ECL	Leader in computers
Toshiba	7.1 bil	390 mil	5.5%	CMOS, MSI-LSI (16K static) (64K) Consumer linear CMOS-MPU SOS (recent investment)	Diversified systems, esp. consumer, bus. systems, instrumentation, appliances, and electrical equipment

Mitsubishi	3.9 bil	150 mil	3.8%	Industrial/consumer linear 64K RAM entrant some ECL	Diversified systems, small bus. computers, industrial & heavy electrical equip., medium appliances
Matsushita	9.8 bil	125 mil	2.3%	Consumer linear new 64K static RAM (strategy shift)	Leader in Consumer & appliances, home computers

the major Japanese firms slant their semiconductor production mix to meet the needs of the different markets which their systems products serve. This suggests that the Japanese firms have also rationalized their semiconductor device production as a logical outgrowth of specialization in final systems markets. Such component-product rationalization among Japanese firms apes the market segmentation that can be found among merchant U.S. firms serving different systems markets in the U.S. Thus, the three leading Japanese exporters of semiconductors to the world merchant market -- NEC, Fujitsu, and Hitachi -- are the firms whose systems capability in computers and communications use technologically advanced MOS LSI and bipolar devices.

However, while production mix correlates strongly with system product markets, internal consumption by the largest firms of their captive production is relatively low.[17] Approximately 21 percent of the value of production is consumed internally by the ten largest producers. (The figure varies among firms. NEC, for example, internally consumes only 16 percent of total sales, while Fujitsu's internal consumption rate rises to perhaps 50 percent, which suggests a primary orientation toward computer sales.) Moreover, internal consumption is particularly low -- 10 percent on average among the top four firms in 1979 -- in MOS devices.[18] Such low internal consumption figures might seem peculiar because these same producers are also the largest consumers of domestic semiconductor devices. Indeed, the top ten firms consumed at least 60 percent of total Japanese domestic production, and the percentage of their consumption of the most advanced IC devices is undoubtedly even higher.[19] This juxtaposition of low internal with high overall consumption suggests that Japanese firms engage in a significant amount of trade themselves.

The implications of such inter-company trade are important and mesh neatly with the observation that component specialization occurs among Japanese firms. As we have seen the systems of each firm strengths rest in overlapping final markets. A more sophisticated specialization in certain devices and technologies may occur among Japanese firms in which they supply each other with semiconductor devices to meet the component needs of their overlapping systems products. Such specialization would enable sophisticated rationalization of device production among the different firms. Indeed, one Fujitsu executive admitted that Japanese semiconductor firms have engaged in this kind of specialization in certain components: "In a small market like Japan's, it is the only way to attain scales of production."[20] As the quote suggests, the effect of such rationalization would be to enable each firm to maximize scale economies and move further down the learning curve in each of its devices than would be possible in the absence of rationalization and inter-company trade. It should be noted here, however, that such interfirm trade in components necessary for specific final systems products may occur only minimally among the few direct competitors in those specific final market subsegments. Thus NEC may be more likely to buy bipolar logic circuits from Fujitsu than from Hitachi, which is a more direct competitor in computer market subsegments. However, the result of rationalization, wherever it occurs, is cheaper devices and cheaper systems that use these devices.

There is a crucial point to be made from the fact that the largest firms control over 60 percent of Japanese semiconductor consumption (and a higher percentage of advanced IC consumption). Such dominant power over demand in the domestic market for semiconductors enables the largest firms to control the pace and direction of growth in that market. By altering the composition of their production and demand, these firms can control the share and composition of imports entering their domestic market. During the 1970s, U.S. firms succeeded in penetrating the domestic Japanese market primarily with advanced product innovations that Japanese firms were not yet producing. As Japanese firms became competent in the production of such devices, there was a characteristic experience for exporting U.S. firms.[21] Their shares of the Japanee market in such devices leveled off or declined -- even as domestic Japanese demand grew explosively -- as the major Japanese firms replaced U.S. imports with devices produced internally and by other Japanese firms. This pattern could be no more than a straightforward import substitution. But at the very least, rationalized control over both production and consumption among the major Japanese firms allows them to control the composition and share even of fully competitive U.S. imports that enter their domestic market. Table 6 gives a rough indication of this overall ability to control imports and consumption. It will be elaborated in Chapter Three along, with the story of a particular device, the 16K RAM (which accounts for the 1978-1980 pattern shown in Table 6). In short, we suggest that collaborative actions of the major Japanese firms may now enable them to take over the role of doorman, played so effectively by the state in other industries and in their own industry's early development (see Section II).

The ability of the largest Japanese firms to use their domestic market to increase their competitiveness is enhanced by certain features of the overall domestic Japanese industrial and financial structure.[22] Each of the top six Japanese semiconductor companies is tied to a Keiretsu, a conglomerate industrial grouping of companies arranged around either a single large bank or large industrial firm (or several firms).[23] The Keiretsu's form ranges from groups with close inter-company ties to looser, basically financial arrangements. Keiretsu members are bound by equity cross-ownership and interlocking management, financing, and buying-selling arrangements. Another set of inter-company ties that tend to assist

Table 6

CONSUMPTION OF INTEGRATED CIRCUITS IN JAPAN BY VALUE

(billions of yen)

Year	Domestic Consumption	Imports	Imports as % of Domestic Consumption	% Change in Imports from Previous Year	% Change in Consumption Previous Year
1975	160	50	31%		
1976	252	74	29%	48%	57.5%
1977	272	64	26%	(13.8%)	(0.4%)
1978	306	68	22%	6%	26.4%
1979	403	111	27%	63%	31.7%
1980	527	118	22%	6%	30.8%

SOURCE: Figures through 1978 based on data from The Consulting Group BA Asia Ltd, 1980; MITI, Ministry of Finance figures from 1978-1980 from BA Asia Ltd., 1981 (unpublished).

company stability is provided by equity cross-ownership outside of the Keiretsu structure, for a majority of company stock in Japan is held by other companies or banks.[24] The Keiretsu structure itself provides important advantages for the Japanese electronics firm that can draw on its resources. First, the Keiretsu members provide an important internal market for the firm's products (as, for example, when the Dai-ichi Bank replaced its IBM banking system with a Fujitsu product). Second, each Keiretsu usually includes a large trading company which is frequently used by Japanese firms to perform overseas sales, distribution, and financing. The trading company thus provides increased access to international semiconductor markets.

Although the infrastructural features described above are important, the most significant advantage offered by the Japanese industrial and financial structure compared to its U.S. counterpart is a stable availability of capital for continued growth -- the basic need for semiconductor companies whose markets are expanding and whose products are changing rapidly. The point requires detailed elaboration because stable access to capital would seem to be an odd attribute, given the financing structure of the Japanese industry: as every observer has noted, the Japanese semiconductor companies, with the exception of Matsushita, have debt-to-equity ratios of 150 to 400 percent, compared with U.S. firm ratios of 5 to 25 percent. In an industry as volatile as semiconductors, where innovation can easily upset the plans of corporate investment, such high debt-equity ratios, with their attendant fixed costs, would normally imply instability rather than stability in the availability of capital. The more volatile an industry, the riskier it is for the lender and the less willing he will normally be to lend. What, then, are the infrastructural advantages that mitigate the risk of carrying debt in Japan and that provide Japanese firms stable access to debt capital?

It should first be noted that Japan's remarkably rapid postwar development was of necessity debt-financed. Such rapid expansion could not be sustained from internal profits alone, and the state could control the allocation of debt in a way that it could not control equity. The state indirectly influenced capital allocation toward favored industries, and as Ueno has shown, private lending followed shifts in public lending. "Broadly speaking, the total supply of funds in Japan was controlled by the Bank of Japan, the level and structure of interest rates were artificially regulated by the Ministry of Finance, and private funds were allocated, under the guidance of public financial institutions, by city banks which competed for market shares."[25] Corporate debt was shared by the banks, which diffused the risk to each. But collapse of a highly levered firm could threaten the banks as well as the company and its suppliers. Since a bank collapse could spread throughout the economy, company troubles became a matter of public policy. At bottom, then, despite the risks of high leverage, the resulting system is stable because government concern with the well-being of firms in favored sectors, like semiconductors, is taken as an implicit guarantee of loans made to them.[26]

The long-term risk born by lenders is thus reduced by the structural participation of the Japanese government, working through the Bank of Japan, in assisting financially troubled firms. In particular, close cooperation and financial assistance from lending banks and the government enables financially troubled Japanese firms to restructure their finances and operations without the threat of loan foreclosure leading to financial collapse. Lending risk is further reduced by a number of additional structural features. As the Chase study noted: "To the extent that a Keiretsu bank directly or indirectly owns a significant interest in the shares of a borrower, it has a continuing voice in establishing corporate policy and direction. This control, coupled with the assurance of financial assistance or loan guarantees from the borrower's Keiretsu reduces the risk taken by lenders."[27]

The huge relative size and product line diversification of the Japanese electronics firms also make them a more secure investment risk. Indeed, the structure of market rationalization and oligopolization may also mitigate risk, because firms are less exposed to competitive failure in the market segments they dominate. Also, these Japanese firms normally hold relatively large portfolios of cash, time deposits, and securities. Large time deposits held in lender banks compensatorily balance the loan exposure of these banks. Large security holdings of relatively liquid assets mitigate investment risk. In sum, low risk for investors means greater willingness to lend, and that translates into relatively stable access to debt capital for Japanese semiconductor firms. Note, too, that these infrastructural features which make Japanese firms low-risk investments also appeal to U.S. investors. U.S. banks which lend to Japan understand that the Japanese government and the Bank of Japan are the ultimate sources of security for U.S. bank loans. Here, the Japanese domestic structure provides important advantages for Japanese firms that compete with U.S. firms for international debt capital from "American" multinational banks.

Finally, of course, the large diversified operations of the Japanese electronics companies add to the stability of capital. Funding of electronics projects may be generated by other operations of the corporation. Profits earned in older, declining sectors may be used to finance expansion of the growing operations. The money may be used directly or to make interest payments on debt incurred in financing expansion.

From the perspective of the firm, the stable availability of capital provides crucial advantages for growth and competitive development. The stability of their capital allows Japanese managers to use a longer planning horizon. They can make commitments to projects that may yield returns only after many years. Such projects may of course range from research and development to capacity expansions to market share battles. In that regard, the extensive use of bank financed debt provides additional freedom to Japanese managers. The banks can give them commitments for a series of loans over many years. The funds which the corporation will have available are not dependent on the immediate earnings of its operation or the price of its stock, as in the United States. Short-term fluctuations in the companies' operations will also be more easily explained and communicated to a small group of cooperative bankers than to participants in an impersonal capital market.

By contrast, the availability of capital is much less stable for U.S. firms, who raise most of their capital through retained earnings and equity investment (as their debt-equity ratios suggest). Since U.S. merchant firms lack those infrastructural advantages that mitigate the risk of carrying debt in Japan, they simply cannot achieve comparable debt levels: lenders would see the risk as so extreme that they would simply refuse to provide capital. Furthermore, U.S. firms operate with certain disadvantages compared to the Japanese industry. The financing of projects from current earnings could well force a firm to forgo promising projects, which would ultimately yield market share and profits, because of a current slump in sales. Long-term planning becomes much more difficult. Moreover, a return to the equity markets might not provide a meaningful choice much of the time. New equity issues must be timed to coincide with variable evaluation of the stock in the market. High stock prices may be poorly correlated with a firm's internal requirements for capital. U.S. firms must also be sensitive to the demands of shareholders, who want quarterly improvements in earnings to raise the price of shares and generate higher dividends. The firm may be unwilling or unable to inform the public of its long-term projects and thus unable to prevent a fall in the price of shares when current earnings falter. A reduction in the value of the stock decreases the ability of the firms to raise not only equity but also additional debt. At the extreme, a sustained decline in the price of the stock may even lead to a takeover of the company by unfriendly outsiders.

It should be noted here that aside from the advantages provided by stable access to debt capital, Japanese firms may also enjoy access to cheaper capital. This, of course, is the central claim of the Chase study.[29] In general, capital would be cheaper for Japanese firms if, discounting inflation, debt in Japan is cheaper than equity in the United States -- that is, if interest rates in Japan on long-term debt (the "cost" to the firm of debt) are lower than the return on investment demanded by U.S. equity investors (the "cost" to the firm of equity). In fact, the cost of capital may be cheaper for Japanese firms given their respective debt-equity ratios, because under U.S. tax law, as in Japan, returns to equity investors come out of taxed income while interest payments on debt are deductable as current expenses. Moreover, given the size and diversity of the Japanese electronics firms and the structural advantages underlying capital stability, the cost of debt to them should also be lower than to U.S. firms. Since large size, diversification, and a tacit government guarantee against failure reduce the likelihood that Japanese firms will be unable to repay a loan, lower interest costs should result. Indeed, the size discrepancy alone between most Japanese firms and U.S. merchant firms suggests that capital will be cheaper for the Japanese firm. The risk to lenders is generally perceived to be smaller when financing a $100 million expansion for a corporation with $2 billion in assets than when financing the same expansion for a corporation with only $100 million in assets.

Cheap and available capital is a special advantage in an industry like semiconductors. As that industry has matured, the contribution to total device cost that comes from capital equipment has increased. In turn, the cost of capital has become a much more significant component of final product cost. For example, in the early 1970s the ratio of capital investment to annual revenues for wafer fabrication was on the order of approximately 1:15. That ratio for the latest generation 64K devices is now on the order of 1:2.5.[30] To the extent that available capital is cheaper for Japanese firms, the increasing contribution of capital equipment to cost puts those firms in a superior competitive position, given their longer planning horizons and relatively lesser need to generate short-term earnings. Simply stated, they can afford to compete directly through product pricing. If their capital is cheaper, their final product will also be cheaper. And this result will be increasingly true as the contribution of capital to cost continues to increase. We should note here that this trend is generally true of most technology-intensive industries. Indeed, the Japanese may well have recognized the point when they reconstructed their financial system in the postwar period to generate more cheap capital for favored growth industries.

Whether or not capital is cheaper, the fact of relatively stable supply gives Japanese semiconductor firms an advantage in their international competition with U.S. firms. (If capital is indeed significantly cheaper, the Japanese advantage would of course be enhanced.) Japanese firms can finance R&D and capacity expansion, can engage in price competition to expand market share, and can finance penetration of foreign markets with relative unconcern for current earnings, even in a recessionary environment. By contrast, growth, development and the ability to compete over market share are all less stable for U.S. firms because they are subject to the vicissitudes of the business cycle. In relative terms, U.S. firms must be very profitable to attract or generate sufficient capital to grow and compete, because they lack the infrastructural advantages of a stable capital supply.

We may now infer the implications of the domestic Japanese market, industry, and financial structures for the international competitiveness of the Japanese semiconductor-electronics industry. As in numerous other Japanese industrial sectors, vertical integration, oligopolization, and rationalization stablize the domestic market environment and permit the Japanese firms in this industry to build massive production volumes in devices and systems destined for export. Control over access further stabilizes the domestic market and prevents U.S. firms from consolidating their innovations and victories in the international marketplace into long-term advantage in the Japanese market. The domestic market thus serves as a stable, mass production base from which to launch penetration of foreign markets, particularly, U.S. markets. Stability of capital secures the domestic base and underwrites the Japanese ability to bear short-run adjustment costs in order to gain increasing shares of foreign markets over the long run. The result, in short, of domestic Japanese systemic strengths is a formidable international competitor in semiconductor markets.

The competitive advantages which the industry's structure and the structure of Japanese business and finance offer Japanese semiconductor-electronics firms mesh neatly with Japanese government policies aimed at assisting the industry's development. During the last decade, Japanese government promotional policies aimed at restructuring the domestic industry, along with protectionist trade policies aimed at limiting foreign access to the domestic market, have nurtured the international competitiveness of the domestic industry. The next section examines the character of this interaction between the industry and the state during the 1970s.

II. State Action and the Promotion of International Competitiveness

By 1968, the Japanese semiconductor-electronics industry was almost completely dominated by production for consumer electronic products. The industry was weak in IC capability, and IC production accounted for only about $24 million out of a semiconductor production of some $252 million, and a total component production of some $1.4 billion.[31] By 1978, roughly a majority of Japanese semiconductor consumption was still in the consumer area, but production for computer and telecommunications needs had brought Japanese firms near international state of the art capability in IC, and especially LSI MOS memory production. IC production accounted for some $1.2 billion out of a semiconductor production of some $2.4 billion and a total components production of some $8.75 billion.[32] This section examines the role played by the Japanese government as doorman and promoter in this rise of the domestic semiconductor-electronics industry to international competitive prominence.

Recall that we have characterized the U.S. semiconductor industry's development as dynamically driven by the interaction between technological innovation and market development. The attractive growth potential of new markets opened up by diffusion of technological innovations generated to meet the needs first of the military, and then of computer and consumer markets, has been a central dynamic. By contrast, the relative weakness of Japanese markets in computers and telecommunications, and the complete lack of military demand, meant that the domestic semiconductor industry's development was not pulled toward innovation except in consumer products. This situation posed a central dilemma for Japanese policy-makers. Under conditions of freetrade and open market access, they faced a risk that U.S. firms might dominate domestic Japanese markets in semiconductors, computers, and telecommunications. If they protected their markets and denied U.S. firms open access, they risked severe technological backwardness in those sectors. The solution the policy-makers chose was characteristic of postwar Japanese development strategy. They used trade policy to limit foreign penetration of the domestic market while deploying a range of financial and promotional policies to assist the industry's growth. Simultaneously, Japanese firms purchased huge amounts of foreign technology, mostly from the United States, and used their strength in consumer products to subsidize a limited price competition with U.S. firms in international semiconductor markets. Only after 1975, when Japanese firms had grown in their technological competence and domestic market dominance, did the government begin to move toward a partial dismantling of the restrictions on foreign penetration.

In 1968, the estimated share of Japanese firms in their domestic semiconductor market was as follows.[33]

Hitachi	23%
Toshiba	21%
Matsushita	15%
Sanyo	13%
NEC	7%
Kobe Kogyo	3%
Mitsubishi	3%
Sony	2%
Fujitsu	1%
Other, including imports	12%

This list suggests the extreme degree to which Japanese production was dominated by a consumer-electronics orientation. Note in particular that NEC, the industry's largest producer of semiconductors and integrated circuits at the end of the 1970s, had only a 7 percent market share in 1968. At that time also, NEC was the Japanese industry's largest producer of ICs, which suggests the degree to which IC production was a relatively insignificant segment of total semiconductor production. Note also that Japan's largest computer manufacturer at present, Fujitsu, accounted for only 1 percent of semiconductor production in 1968. Fujitsu did not produce semiconductors for consumer product markets until its merger in 1968 with Kobe Kogyo, which again suggests that firms which did not produce semiconductors for consumer products could not grow effectively in the 1960s.[34] In 1968, consumer products dominated the industry's electronic systems sales, accounting for at least 60 percent of production. The significance of this domination for Japanese semiconductor production cannot be overemphasized. NEC began limited commercial production of the integrated circuit and the MOS transistor only one year after their commercial introduction by Texas Instruments and Fairchild in the United States. However, with no significant military or computer demand to stimulate the production and innovation of those devices, they remained a relatively insignificant part of Japanese semiconductor production. Thus, by 1968, with a limited IC production worth only $24 million, Japanese semiconductor production was serving its consumer systems strength, and its capability in advanced ICs was weak. It has been estimated that by the end of the 1960s Japanese firms had achieved only rough technological parity with U.S. firms in producing ICs with under 100 gates.[35] Japanese firms lagged in basic LSI research and capabilities and were simply not an important factor in international competition.

The Japanese developmental strategy of creating comparative advantage in advanced technology sectors centered in this period on promoting the domestic computer industry.[36] Earlier attempts at promotion had been relatively unsuccessful, and innovation by U.S. firms in integrated circuit technology threatened to increase the U.S. advantage in computers. If the Japanese development strategy was to succeed, Japan needed a competitive semiconductor sector. Thus, during the 1960s and the early-mid 1970s the Japanese government, principally through MITI, sought to build a competitive semiconductor industry by limiting foreign competition in the domestic market and acquiring foreign technology and know-how. Foreign investment laws created after World War II required the Japanese government to review for approval all applications for direct foreign investment in Japan. The government consistently rejected all applications for wholly owned subsidiaries and for joint ventures in which foreign firms would hold majority ownership. It also restricted foreign purchases of equity in Japanese semiconductor firms. Simultaneously, the government limited foreign import penetration of the home market through high tariffs and restrictive quotas and approval-registration requirements on advanced IC devices in particular. For example, until 1974, ICs that contained more than 200 circuit elements simply could not be imported without special permission. Penetration was also managed by exclusionary customs procedures and "Buy Japanese" procurement and "jaw-boning" policies.[37]

The price to U.S. firms for limited access to the Japanese market was their licensing of advanced technology and know-how. This, too, was regulated closely by the Japanese government, whose approval was required on all patent and technical-assistance licensing agreements. Since MITI controlled access to the Japanese market and its approval was required for the implementation of licensing deals, it was in the powerful monopsonist's position of being able to dictate the terms of exchange. Its general policy was simple and effective. It required foreign firms to license all Japanese firms requesting access to a particular technology. It limited royalty payments by Japanese firms to a single rate on each deal, thereby pre-empting the competitive bidding-up of royalty rates among Japanese firms. In line with the characteristic emphasis on export strategy, MITI often linked the import of particular technologies to the acquiring firm's ability to develop export products using that technology.[38] MITI also conditioned approval of certain deals on the willingness of the involved Japanese firms to diffuse their own technical developments, through sub-license agreements, to other Japanese firms. The total result of these policies was a controlled diffusion of advanced technology throughout the Japanese semiconductor industry. Tilton gives a convincing measure of the extent of Japanese firm dependence on the acquisition of U.S. technology: by the end of the 1960s, Japanese IC producers were paying at least 10 percent of their semiconductor sales revenues as royalties to U.S. firms -- 2 percent to Western Electric, 4.5 percent to Fairchild, and 3.5 percent to Texas Instruments.[39]

Royalty income may have been substantial for a number of U.S. firms, but market access (with one notable exception) was ephemeral indeed. Diffusion of advanced technology meant an on-going Japanese catch-up, during the 1960s and 1970s, to successive generations of technological innovation by U.S. firms. As this occurred, domestic Japanese production displaced U.S. imports, and U.S. firms maintained Japanese market share only by shifting the composition of their imports toward products which Japanese firms were not yet producing themselves. (The implications and elaboration of this point will be discussed later.)

The one successful entry into the Japanese market by a U.S. firm came when Texas Instruments reached agreement with Sony on a joint venture in 1968. In fact, TI's entry strategy was really a replication of IBM's earlier success at establishing a wholly owned subsidiary in Japan in 1960 in exchange for IBM's industry-leading technology. Indeed, the very existence of the system of control over access and diffusion of technology described above acknowledges IBM's success at penetrating and then dominating the Japanese computer market. The Japanese did not want to allow IBM's success to be repeated by other foreign firms in other sectors -- especially a sector as crucial as semiconductors. In that light, the TI story is significant for what it reveals about Japanese government policies, attitudes, and strategy in this period.[40]

Texas Instruments petitioned the Japanese government for a wholly owned subsidiary in the early 1960s, and was offered a minority-share joint venture which it rejected. Its chief bargaining chip during these negotiations was its continuing refusal to license its critical IC patents to Japanese firms without gaining in return a substantial production subsidiary in Japan. NEC and the other firms sub-licensed to it were in fact producing ICs based on technology developed by TI and Fairchild, through an NEC-Fairchild licensing agreement. However, because the TI-Fairchild patent accord explicitly excluded Japan, those Japanese firms were not protected, as Fairchild licensees were in Europe, against patent-infringement suits brought by TI. The Japanese government stalled approval of TI's patent application in Japan, and this enabled NEC and the other firms to play domestic technology catch-up, thereby forcing TI to negotiate for quicker access. The Japanese government then held up Japanese exports of IC-based systems to the U.S. because TI threatened infringement action. A compromise was finally reached in which TI got a 50 percent share of a joint venture with Sony. In return, it agreed to license its IC patents to NEC, Hitachi, Mitsubishi, Toshiba and Sony, and agreed further to limit its future share of the Japanese semiconductor market to no more than 10 percent. TI bought Sony's share of the joint venture in 1972, and through 1980 remained the only U.S. merchant firm with a wholly owned manufacturing subsidiary in Japan.

The strategy of technological diffusion and limited market access, implied in the TI story and elaborated before, enabled Japanese firms roughly to mimic technological developments in the United States. However, the pace of semiconductor innovation in the United States was accelerating, driven by the computer market, and Japanese semiconductor-computer firms were lagging far behind. This was occurring, moreover, despite a decade or more of Japanese government promotional policies aimed at the development of a domestic computer sector that could pull semiconductor capability into rapid growth. These policies included the creation of a specialized infrastructure of advisory bureaus, promotional institutions and laboratories, preferential government procurement, credit allocation and tax incentives, and direct and indirect R&D subsidization.[41] As Gresser summarizes: "By 1969 it was obvious that the six major computer and semiconductor manufacturers were operating inefficiently. MITI well understood that if the Japanese firms continued to produce similar systems for a domestic market a fraction of the size of the U.S. market, the Japanese industry would not be able to compete internationally despite the most generous government assistance. MITI therefore decided to expedite the development of core technologies and to realign the industry."[42]

Through 1970, direct Japanese government subsidization of advanced IC and production technology R&D by Japanese firms was not significant, although significant basic research was carried out in government and NTT laboratories. Moreover, private company funding of R&D was not at all competitive with U.S. firm spending. Indeed, in the early 1970s, combined spending by Fujitsu, Hitachi, and NEC on semiconductor <u>and</u> computer R&D was less than Texas Instruments' R&D budget.[43] It was, then, toward greater subsidization and coordination of R&D in computer, LSI, and production technology that the government turned in order to pull Japanese firms toward greater international competitiveness.

In 1971 the Japanese government introduced a national policy for the promotion of certain industries, which targeted the development of advanced technologies.[44] This Law for Provisional Measures to Promote Specific Electronic and Machinery Industries designated three strategic categories: (1) advanced technologies needing direct R&D support -- especially technologies like LSI, where Japanese firms lagged considerably behind U.S. firms; (2) production technologies, like those demanded in LSI production, which were intimately linked to device-system cost, quality, and performance; and (3) high-volume production technologies. MITI was given responsibility for financing R&D and rationalizing production. By 1977 over sixty different projects had received total financial support in the multi-hundred million dollar range, in such areas as E-beam exposure and LSI production equipment, high performance discrete devices, basic materials research, low power-high performance ICs, and VLSI.

MITI's attempt at restructuring the domestic Japanese industry was centered on promoting of internationally competitive computer production. The target of the reorganization attempt was IBM's 370, which dominated world mainframe computer sales and utilized IC but not LSI technology. Significant entry into world computer markets could be gained by leapfrogging technology and introducing an LSI-based computer system. Semiconductor R&D funding was aimed, therefore, at final usage in next-generation computers. It was hoped that once a growing and competitive computer sector took off, its needs would stimulate semiconductor development. The six major semiconductor-computer manufacturers were accordingly the focus of MITI's attempt at structural realignment.

In 1971 the six semiconductor-computer firms formed three paired groups: Fujitsu-Hitachi, NEC-Toshiba, and Mitsubishi-Oki. Through these pairings MITI hoped to force a specialization of development efforts and long-term competitive segmentation of the computer market. Toward that end, each group received subsidies totaling some $200 million dollars between 1972 and 1976. Also in 1971, MITI and Japan's Electronics Industry Association formed an LSI cartel among the ten major semiconductor producers. Its purposes were to standardize LSI basic structures and packages, to streamline and standardize manufacturing processes, and to develop LSI test equipment.[45] This cartel may indeed have been the seedbed for the device specialization among the major Japanese firms discussed in Section I.

These efforts to shift semiconductor production and development to meet the needs of Japan's fledgling computer industry must be located within the context of a continuing demand pull from consumer electronic markets. Through 1979, consumer discrete semiconductor devices and consumer linear integrated circuits accounted for well over 50 percent of the value of Japanese domestic semiconductor production. Moreover, all of the major producers, with the exception of Fujitsu, were heavily involved in calculators and consumer linear ICs.[46] During the late 1960s, the move abroad of major U.S. semiconductor and consumer electronic companies undercut part of the Japanese comparative advantage in consumer electronic products. As LSI technology penetrated consumer product markets in the early 1970s, particularly in calculators and watches, the U.S. shift abroad and the relative technological weakness of Japanese producers presented a serious challenge to their strength in international consumer markets. The case of calculators is suggestive.[47] In 1971 Japanese firms held approximately 85 percent of the domestic U.S. market for calculators. By 1974, under severe price competition from U.S. producers, that share fell to 25 percent. At the beginning of the period, Japanese firms like Sharp, Sanyo, Canon and Casio entered into long-term contracts with Rockwell, GI, Texas Instruments, and Fairchild for calculator chips and technical assistance to close the technology gap. Also during that period, the largest Japanese semiconductor producers capitalized on their emerging, MITI-coordinated, LSI capability to produce competitive calculator chips. After 1974, when semiconductor-calculator technology stabilized and production costs equalized, the Japanese share of the U.S. market began to rise again.

By the end of 1975, the cooperative computer efforts, MITI's subsidization and coordination of R&D for LSI, and shifting consumer product market demand had succeeded in raising the value of the industry's IC portion of domestic semiconductor production from 27 percent in 1971 to about 42 percent.[48] While MITI's promotion of LSI capability had worked well, its attempt to consolidate the computer operations of the six semiconductor-computer companies had largely failed. The attempt at consolidation did produce joint marketing ventures, notably (in 1974) NEC-Toshiba Information Systems (NTIS) and Fujitsu-Hitachi's ACOM-HITAC; and coordinated R&D had benefited each of the participating firms. However, there was continuing strong competition in computer system products between the three groups and between each group's members, and the six firms remained largely independent. More important, by mid-1975 it was clear that the MITI-industry effort to leapfrog into an internationally competitive position in computers had fallen victim to changes in the international computer market.

The most significant market development was the introduction by U.S. computer companies of low-cost, LSI-based plug-compatible mainframes (PCM). PCMs were made economically possible by advances in LSI technology and the continuing decline in cost per function generated by them. They offered superior performance per dollar and generally utilized IBM's software. PCMs thereby reinforced IBM's international dominance in software, and consolidated for U.S. firms the LSI-based international computer market-segment toward which Japanese efforts had been aimed. Innovation in the market thereby rendered

Japanese goals obsolete. This point is important, for it reveals a potential competitive weakness amid this Japanese industry's general, high-volume production strategy (discussed in Section I). Quite simply, competitive innovations in the market can lay waste to massive sunken investment in the production of devices and systems based on an older technology. Of course, the ability of Japanese firms to recuperate in their controlled domestic market and to draw on stable sources of capital can mitigate the long-term impact of competitive innovations from abroad. (These points will be elaborated in Chapter Three.) In any case, if Japanese computer companies wanted to break into the international market for computers in a big way, they were going to have to do so on the basis of the next generation of semiconductor-computer technology -- VLSI. (Note that a complementary response would be acquisition of a growing PCM firm, which Fujitsu did with Amdahl in 1976.)

It is within the context of these events that MITI's liberalization of some of the restrictions on foreign access to the Japanese market in semiconductors and computers, announced on December 24, 1975, must be understood. During the previous four years of market protection and industry promotion, Japanese semiconductor-computer firms had developed a significant LSI capability, and by 1976 they dominated their domestic market in all but the most advanced IC devices. They had also succeeded in raising their share of the domestic installed base of general purpose digital computers to over 60 percent. They were thus in a dominant position in their domestic market at a time when the issue of a protected domestic base from which to enter international competition in LSI-based mainframes had been significantly mooted by international market developments. Liberalization of trade in components and computers, with continued structural control over the character and composition of penetration, thus made sense --

especially when combined with a program of promotion aimed at VLSI. Moreover, liberalization also made great political sense because the industrialized West was in the midst of a mid-decade cycle of recession and recovery, and Japan was exporting excess domestic capacity in a range of economic sectors (such as steel and consumer electronics). The beginning clamor in the United States and Europe for domestic protection against Japanese imports could be best countered by liberalizing access to the Japanese market. In preparation for liberalization and the push toward advanced LSI, the Japanese semiconductor-computer industry regrouped in late 1975.[49] Fujitsu, Hitachi, and Mitsubishi formed a joint venture, Computer Development Industries, Ltd., to develop VLSI and the next generation of computer prototypes. Mitsubishi also joined with Hitachi and Fujitsu in their MITI-sponsored research, and Oki, no longer among the elect, split off to specialize in terminals. Also in 1975 NTT formed an LSI group with Hitachi, Fujitsu, and NEC to develop advanced communications systems. Just after liberalization, the corporate articles of NEC-Toshiba Information Systems were amended to emphasize VLSI development, and a VLSI lab was established within NTIS. Finally, of course, MITI, NTT, and the five major semiconductor-computer firms organized the VLSI project, and in March 1976 they formed the VLSI Technology Research Association.

We should note here that the movement toward trade liberalization in Japan, quite apart from the debt it owes to pressure from the United States, marks a divergence between Japanese state and business strategies. The movement toward trade liberalization should be seen in part as the result of Japanese business opposition to MITI's continuing protection. As Japanese firms grow in international competitive power, they view MITI's protectionist policies, which can generate retaliation, as a probable limitation on their ability to expand competitively abroad. How far formal liberalization goes will depend in part upon the extent to which such pressure from Japanese business prevails.[50] We remain skeptical about the extent and impact of liberalization, however, especially given the collaborative ability of some Japanese firms to play the role of doorman. To the extent that an industry like semiconductors, through its successful development, begins in this way to slip away from state control, state promotional policies provide a continuing opportunity to resassert the government presence.

In this context, trade liberalization in 1976 -- contemporaneous with the Japanese industry's regrouping -- was ambiguous. Gresser summarizes:

> Foreign capital investment was greatly expedited and the burdensome import quota system was eliminated. Trade and investment in computers was completely liberalized on schedule by April 1976. . . .The Cabinet released the following statement . . . "the Government . . . will keep an eye on movements in the computer market so that liberalization will not adversely affect domestic producers nor produce confusion."
>
> To mitigate liberalization, the government expanded its support for research and development of "core" technologies; foreign penetration of the Japanese market was checked, principally by limiting foreign procurement opportunities and by other administrative means.[51]

Such policies for mitigating the impact of liberalization generally continue in force at present. Moreover, as suggested earlier, the ability of the largest Japanese semiconductor firms to collaborate in playing the role of doorman acts structurally to mitigate the impact of liberalization on the domestic market. In the late 1970s, then, both trade policy and industry structure combined to regulate access to the domestic market for semiconductors.

The VLSI program was the major promotional vehicle to assist the competitiveness of the Japanese semiconductor-computer firms during the late 1970s. As suggested before, the program was aimed at developing semiconductor technology for the next generation of computers. This meant developing state-of-the-art capability in the production of both memory devices and logic circuits. Figure 1 gives a rough organizational picture of the project.[52]

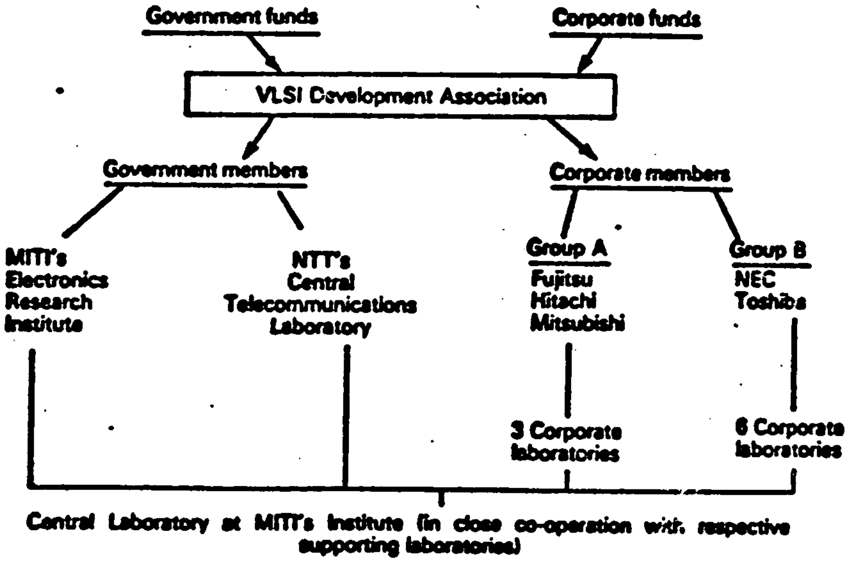

FIGURE 1: Very large scale integration project

The stated aims of the program were: (1) development of micro-fabrication methods to handle sub-micron lithography, especially electron beam lithography; (2) development of low-defect large diameter silicon wafer substrates; (3) development of improved computer-aided design technology; (4) development of improved LSI micro-fabrication processing techniques and equipment; (5) development of VLSI evaluation and testing techniques and equipment; and (6) definition of logic and memory devices that could utilize 1-5.[53]

As this list suggests, much of the VLSI program was aimed at catching up to the U.S. industry's capabilities in advanced IC process technology. Toward that end, as described in the introduction to this chapter, a significant portion of the program's funding was spent in the United States to purchase production and test equipment. Such purchases were not surprising, for in the first years of the VLSI program, imports of foreign (mostly U.S.) production equipment accounted for an estimated 70 to 80 percent share of the domestic Japanese market.[54] Japan's indigenous capital equipment industry for semiconductor manufacture is still relatively small, but its fastest growing segment appears to be controlled by the major Japanese semiconductor producers. Since the import share of production equipment fell to about 50 percent in 1980, one result of the VLSI program was a strengthening of the domestic Japanese infrastructure in production and test capabilities. Indeed, the general manager of NEC's VLSI development division admitted, for example, that his firm would have had to spend five times as much on the development of electron-beam technology without the VLSI program.[55]

An equally important impact of public subsidies and nonduplicative research coordination in the VLSI program was the release of company funds for capacity expansion (and eventual penetration of the U.S. market). In 1977, the top six Japanese semiconductor producers spent a total of some $116 million on new plant and equipment.[56] That figure rose to an estimated $212 million in 1978, with NEC accounting for $66 million and Fujitsu for $42 million. Most of the investment made by NEC and Fujitsu went to build IC and especially MOS RAM production capacity. In 1979, spending by the top ten semiconductor producers in Japan climbed to an estimated $420 million dollars. This pattern of heavy spending was a response to increasing demand in the domestic Japanese market and to rapidly growing export opportunities, which were carefully nourished by Japanese companies.

The exploitation of export opportunities was particularly apparent in the domestic U.S. market. During the first two years of the VLSI program, the major Japanese firms (led by NEC and Fujitsu) rapidly built up a distribution system in the United States.[57] Prior to 1976, major U.S. distributors had been hesitant to serve Japanese producers who could not meet commitments for large volumes and continuous supplies of high-margin memory and MPU devices. This situation changed as the Japanese rapidly expanded production capacity and advanced their technology. By the middle of 1977, NEC, Fujitsu, Hitachi, and Toshiba were all moving toward broad-based distribution channels, which were frequently managed by marketing experts recruited from U.S. companies. NEC, Fujitsu, and Hitachi each set up wholly owned domestic U.S. subsidiaries for marketing LSI products. Toshiba sold its LSI devices through an OEM sales group attached to Toshiba America Corporation. NEC and Fujitsu each developed extensive ties to a large number of U.S. distributors, which gave them access to most regions of the country. By the beginning of 1978, when MOS memory demand jumped in the United States, Japanese firms were well placed to take advantage of the situation.

Japanese firms could take advantage of export opportunities in the U.S. market because the growth of production for their own domestic market had brought them toward international state-of-the-art capability by the late 1970s. Tables 7, 8, and 9 compare the composition of domestic Japanese IC production, by units and value, in 1974 and 1978; the composition of Japanese IC consumption, by units and value, in 1979; and the percentage of Japanese IC consumption in 1979 by major market segments.

Table 7

COMPOSITION OF DOMESTIC JAPANESE IC PRODUCTION, 1974 AND 1978.

(units in millions, values in millions of dollars)

	1974				1978			
	Units	% of Units	Value	% of Value	Units	% of Units	Value	% of Value
TOTAL IC	340	100%	$ 439	100%	1,063	100%	$1,260	100%
Linear	154	45%	$ 110	25.2%	561	53%	$ 363	29%
Digital	152	45%	$ 273	62.3%	450	42%	$ 769	61%
bipolar	(106)	(32.5%)	$(109)	(25%)	(222)	(21%)	$(183)	(14.6%)
MOS	(46)	(13.5%)	$(163)	(37%)	(228)	(21%)	$(585)	(46.4%)
Hybrid	34	10%	$ 54	12.4%	52	5%	$ 126	10%

SOURCE: The Consulting Group, BA Asia Ltd., 1979, pp. 89-94. Yen/dollar conversion at 286/1 in 1974 and 212/1 in 1978.

NOTE: Figures may not add due to rounding.

Table 8

COMPOSITION OF DOMESTIC JAPANESE IC CONSUMPTION, 1979

(units in millions, values in millions of dollars)

	Units	% of Units	Value	% of Value
Total ICs	2056	100%	$1,604	100%
Consumer Linear	700	34%	$ 300	19%
Other Linear	150	7%	$ 80	5%
Digital Bipolar	550	27%	$ 304	19%
Digital MOS	576	28%	$ 760	47%
Hybrid ICs	80	4%	$ 160	10%

SOURCE: BA Asia Ltd., 1980, p. 113. Yen/dollar conversion at 250/1.

NOTE: Figures may not add due to rounding.

Table 9

DOMESTIC JAPANESE IC CONSUMPTION BY MAJOR MARKET SEGMENT, 1979

Market Segment	Percent of Consumption
Consumer	29%
Computer	35%
Communications	6%
Test and Measurement	2%
Calculators	11%
Other (including watches, automotive)	17%
Total	100%

SOURCE: Same as Table 8.

These tables reveal important shifts in the growth and composition of Japanese production. The quantity and value of Japanese IC production almost tripled from 1974 to 1978. Linear ICs as a percentage of unit production rose to 53 percent. Note that linear ICs are relatively low value-added devices. Since most linear ICs are consumer linear devices, the growth in their production suggests the continued demand pull of the consumer electronics market on the composition of Japanese IC production. Indeed, as Table 9 suggests, consumer electronics, calculators, and watches consumed approximately 50 percent of the ICs that entered the domestic market. The continuing importance of consumer IC consumption and the associated high percentage of linear ICs in the Japanese production mix have important implications for the international competitiveness of Japanese firms. As W. E. Steinmueller has noted: "ICs are not in the forefront of technical advance or potential. . . .(They) do not provide the basis for building Japanese technological parity or advantage in world IC markets. Linear IC production may (however) be an important testing ground for automated assembly or other 'post-fabrication' operations. (Moreover), capacity in linear production is not easily re-tooled to produce digital ICs."[58] To the extent that the consumer sector continues to influence the mix of Japanese IC production, Japanese firms will be forced to allocate their resources to lower value-added production for consumer markets. Moreover, since 69 percent of consumer electronics production is exported, and international demand fluctuates over time, the inability to retool production capacity may have a cyclical impact on the earnings of Japanese firms.

The consumer market in Japan has centered on the consumption of television sets, stereo components, tape recorders, and recently videotape recorders. The video disc is the next big consumer growth item for both the domestic and the export markets. The 1980 Bank of America study estimates that the domestic production value of video discs in 1982 could be worth about $800 million. This would imply a semiconductor content of some $40 million. With additional continued demand from the calculator and watch markets, it is likely that consumer product markets will continue to exert a strong influence on Japanese semiconductor production, thereby slanting it in the ways suggested above.

The continuing importance of consumer production must be viewed in the context of the rapid growth of digital IC capability between 1974 and 1978. As Table 7 suggests, those years witnessed a rapid changeover from concentration on digital bipolar production to concentration on MOS. (Recall that a comparable changeover occurred by 1975 in the United States.) The relative de-emphasis of bipolar production suggests a strategic evaluation of where the best prospects lie for rapid growth and international competitiveness of Japanese production. The most important market factor in the growth of MOS production was Japan's burgeoning computer industry, which by 1979 accounted for 35 percent of domestic Japanese IC consumption. MOS production is the fastest growing and highest value-added segment of the IC production mix. Moreover, unlike linear ICs, MOS memory ICs are complex circuits that require technically sophisticated design and production capabilities. Technical sophistication here is transferable to the design and production of other complex products, and thereby poses implications for the international competitiveness of Japanese firms. Thus, while the consumer market pulls Japanese producers toward technological complacency, the computer market pulls them toward technological advance. Indeed, the rapid growth of MOS LSI capability to serve domestic computer demand increasingly displaced complex MOS imports to the Japanese market, and forced U.S. firms to shift the composition mix of their exports to supply devices not yet produced in quantity in Japan. Equally important, by 1978 that growth had enabled Japanese firms to enter the U.S. markets for MOS memory and microprocessor devices.

The domestic computer market in 1978 and 1979, by sales value of the major producers, is given in Table 10. The increasing market share taken by domestic firms will probably continue through the 1980s, with a resulting favorable impact on the technological competitiveness of these Japanese semiconductor firms.

Demand from the growing telecommunications sector also stimulated Japanese LSI capability during the middle to late 1970s, and this growth was intimately tied to the policies of NTT (Nippon Telephone and Telegraph). NTT buys almost all of its equipment from NEC, Hitachi, Fujitsu, and Oki (The Big Four), and has also played the characteristic role of doorman for telecommunications. Until the very end of the 1970s, NTT's procurement was completely closed to foreign

Table 10

JAPANESE DOMESTIC COMPUTER SALES
(yen in billions, dollars in millions)

Company	1978	1979
Fujitsu	Y303($1420)	Y340($1360)
Hitachi	Y190($ 896)	Y220($ 880)
NEC	Y167($ 787)	Y200($ 800)
Mitsubishi	Y 45($ 212)	Y 53($ 212)
Oki	Y 48($ 226)	Y 50($ 200)
Toshiba	Y 60($ 283)	Y 55($ 220)
IBM Japan	Y315($1480)	Y324($1290)

SOURCE: BA Asia Ltd., 1980, p. 47.

NOTE: Yen/dollars conversions are 274/1 for 1977; 212/1 for 1978; and 250/1 for 1979. The fall of the yen vs. the dollar in 1979 accounts for the rise in yen value and the decline in dollar value between 1978 and 1979.

firms; moreover, it did not allow the Big Four to use imported semiconductors in the equipment they supplied to them. Hout and Magaziner describe the promotional character of NTT's impact on technological development and market rationalization: "NTT makes all decisions on technical specifications, and engineers of the Big Four manufacturers are invited to develop new equipment partly after basic research is completed by NTT's own engineers. Therefore, all research and development expenses incurred by manufacturers are mostly application and production related. . . .NTT assigns actual production and supply to each manufacturer, depending upon availability of technical capacity and actual performance of the company on past assignments."[59] Under such guidance, the production value of communication equipment rose steadily from under $2 billion in 1973 to over $2.6 billion in 1977.[60] The Bank of America study estimates that communication equipment consumed approximately $235 million worth of semiconductors in 1978, with NEC and Fujitsu combined accounting for about 35 percent of that total.

Apart from financing and directing research and development, NTT also helps indirectly to finance exports. Since NTT negotiates its equipment purchases on a cost plus basis, it acts to provide "monopoly like" prices in a manner similar to U.S. military purchases. The exclusion of foreign procurement stabilizes prices and production volumes. NTT also advances part of the purchase price, thereby providing interest-free loans to the manufacturer. The result is great flexibility in export pricing. As Hout and Magaziner describe the resulting export growth during the 1970s: "Japanese companies got off to a late start in telecommunications exports, in large part because of their undistinguished technology. However, the boom in the OPEC and developing Asian markets in the middle and late 1970s, combined with lower growth at home, brought them into export markets. Exports, only 8 percent of sales in the early 1970s, are now 18-20 percent."[61] The international markets developed during the 1970s can be expected to grow significantly during the 1980s, with a resulting favorable impact on the technological sophistication of the largest semiconductor producers.

The separate but rapid growth during the 1970s of the three markets discussed above -- the consumer, computer, and telecommunications markets -- produced conflicting demands on the major Japanese semiconductor-electronic firms. In conjunction with the MITI and NTT promotional policy actions, the various demands of rapid growth have also been responsible for the specialization of product and semiconductor technology among Japanese firms described at the beginning of this chapter.

Through most of the 1970s, Japanese government policies limited foreign access to the domestic market and ensured that the advantages of rapid domestic growth would accrue mostly to domestic Japanese firms. Growth was underwritten partly through public subsidies but mostly through the stable access to capital delivered by the structure of domestic Japanese business and finance.

By 1978, a decade of Japanese government assistance and protectionist policies had finally coalesced with the growth of domestic IC markets to create a strong domestic semiconductor sector. Moreover, the industry was rapidly expanding its export penetration of important and growing international electronics markets, which further strengthened its semiconductor capability. Through its industry structure and market power, the Japanese semiconductor industry dominated its domestic market, and achieved near state-of-the-art capability in the fastest growing segments of the international IC market. For the first time in history, major Japanese IC firms were positioned to enter world MOS LSI memory markets on a roughly equal technological footing with their U.S. merchant competitors. In the next chapter we shall analyze the ways in which that entry has altered the character of competition in the international market for semiconductors.

Chapter Three

INTERNATIONAL COMPETITION IN INTEGRATED CIRCUITS: A COMPARISION OF U.S. AND JAPANESE STRATEGY AND STRUCTURE

As we have seen, the U.S. and Japanese semiconductor industries proceeded along separate lines of market development in relative isolation from one another during the period 1960-1976. To oversimplify slightly, the Japanese were not capable of penetrating the U.S. market in any significant way, and Japanese state policy permitted U.S. firms neither direct investment nor significant market share in Japan. By the late 1970s, however, the Japanese had successfully established a thriving domestic IC sector to serve growing domestic computer and telecommunications needs. These needs could only be met by producing more sophisticated IC devices like those which dominated IC markets in the U.S. and Europe, and in which, of course, U.S. producers were pre-eminent. This growing convergence in demand for advanced ICs between international and Japanese markets provided the basis upon which international competition among U.S. and Japanese IC producers accelerated in the late 1970s.

I. Japanese Entry and Systemic Strengths in International Competition

From their secured domestic base, the leading Japanese firms entered those international markets in the leading edge of IC memory devices whose standard, commodity-product character had been developed and dominated by U.S. merchant firms. The value of Japanese IC exports to the United States rose from about $50 million in 1977 to just under $300 million in 1980.[1] The value of Japanese IC exports to Europe rose from $12 million in 1976 to about $165 million in 1980.[2] While Japanese IC firms had clearly matured enough to expand competitively in international markets, they apparently chose not to accept the full brunt of competition in their domestic market. The characteristic pattern of organized import substitution continued to limit the domestic Japanese market opportunities of U.S. firms. The available evidence suggests that as Japanese demand for even the most advanced IC devices began to increase, the domestic Japanese market share held by U.S. firms narrowed rapidly.[3] U.S. competitive advantages could not be consolidated into enduring market positions in Japan. Figure 2 gives a rough indication of the pattern of domestic Japanese IC consumption accounted for by imports from U.S.-controlled sources (domestic and offshore facilities combined).[4]

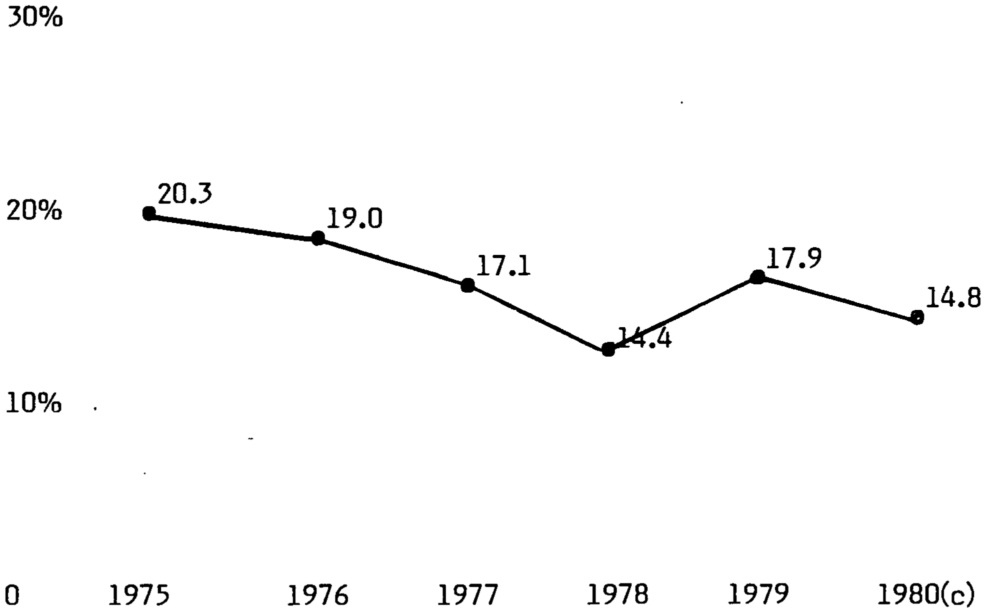

FIGURE 2. Estimated Percentage of Domestic Japanese IC Consumption Accounted for By U.S.-Controlled Imports Into Japan, by value

If U.S. firms were consolidating their product innovation advantages into enduring market positions, we would expect the percentage of consumption accounted for by a progressively higher value-added mix of U.S. exports (into Japan) to increase. As Figure 2 indicates, this has not been the case; rather, a pattern of organized import substitution seems to be implied. The rise in 1979 in the U.S.-controlled import share of Japanese IC consumption is accounted for, in particular, by an increase in 16K RAM sales (to be discussed below).[5] The decline in 1980 again seems to verify the general Japanese strategy discussed above.[6]

Given the controlled nature of access to the Japanese market, the competitive interaction of the U.S. and Japanese semiconductor industries in the late 1970s centered most crucially on Japanese entry to the domestic U.S. market for ICs. The most significant international market battle took place in the MOS memory market, and centered on the domestic U.S. market for 16K MOS RAMS. The price per bit equivalency between 4K and 16K dynamic RAMS occurred in 1978, and with it came a significant and accelerating demand for 16K RAMS. On top of the demand generated by this crossover, IBM entered the merchant market with a huge demand for 16K RAMS to meet the memory needs created by the rapid market acceptance of its new series 4300 computer. The increasing demand for 16Ks was paired in the U.S. market with a significant production capacity shortfall. This stemmed largely from the failure or inability of merchant IC firms to invest in capacity expansion during the 1975 recession, and from their cautious investment policies following the recession. Here, of course, reliance on internal funds and equity markets constrained the business strategy choices of U.S. firms. By contrast, the stable availability of capital for Japanese firms permitted them to engage in a rapid capacity build-up that could support their export strategy. Indeed, in 1978 and 1979, the major Japanese firms strode, in force, into the market gap created by significant undersupply in the domestic U.S. memory market. By the end of 1979, they had taken 43 percent of the domestic U.S. 16K RAM market. Table 11 below summarizes 16K RAM production in 1979, by major producer.

Table 11

16K RAM PRODUCTION, 1979
(thousands of units)

Leaders		Others	
Mostek	16,800	Fairchild	1,900
NEC*	11,300	ITT	1,700
TI	9,000	Mitsubishi*	1,250
Hitachi*	7,100	Siemens	875
Fujitsu*	6,500	Zilog	190
Motorola	4,700	Signetics	175
Toshiba*	3,475	AMD	65
Intel	3,250	Intersil	10
National	3,200	SGS-ATES	3

SOURCE: Dataquest, Inc.

NOTE: Asterisk indicates Japanese firm.

The 16K RAM story offers important insights into the ways in which the Japanese industry's domestic market structure and power give Japanese firms an advantage in international competition. First, in the ways described in Chapter

Two, Japanese firms were better able than U.S. firms to add production capacity and pursue a high-volume production strategy because capital was available and Japanese firms could be relatively unconcerned with current earnings. Second, their characteristic rationalization of production apparently enabled the major Japanese firms to concentrate capacity expansion on the high-volume production of a single memory product -- 16K RAMS -- destined for the U.S. market, while meeting their other product needs through specialization and trade between domestic firms. Third, since they exercised dominant market power over consumption in their domestic market, the major Japanese firms could play the role of doorman and control the growth and composition of imports entering their market. This meant two things. First, until late 1978 Japanese producers apparently used a two-tier pricing strategy. They kept RAM prices high in their controlled domestic market, thereby subsidizing their ability to offer lower prices in the U.S. market. (Prices only came down in response to the ITC's "dumping" investigation, initiated by SIA lobbying in the United States.)[7] More important, as domestic Japanese demand for 16K RAMS rose in 1978 and 1979, Japanese IC firms chose to let <u>imports</u> (mostly from U.S. firms) meet domestic Japanese demand -- and by implication, to meet a part of their own consumption needs. This enabled Japanese producers to divert their own production to the United States in order to increase their share of the U.S. market. Thus, as we have seen, exports by U.S. firms of 16K RAMS to Japan actually <u>rose</u> in 1979. Since the major Japanese producers of 16K RAMS have also dominated 16K RAM <u>consumption</u> in Japan, they have been able to limit and displace future U.S. imports; but we have suggested, this appears to have occurred in 1980. Since a parallel market power is not held by merchant U.S. firms in the domestic U.S. market, Japanese penetration in the U.S. will not be comparably limited and displaced. Thus, the cost to U.S. firms of temporarily increased access to the Japanese market is a significant and perhaps enduring Japanese presence in the domestic U.S. market. The Japanese firms also used the issue of higher quality as an extremely effective technique to help penetrate the U.S. RAM market. A number of U.S. consumers of Japanese 16K RAMs, notably Hewlett Packard and NCR, have suggested that the failure rates of the Japanese product were significantly lower than those of U.S. devices. While U.S. devices met the quality standards of U.S. purchasers, there was unexploited market demand for higher quality devices. Japanese producers correctly appraised the U.S. market and used a higher quality penetration strategy to capture additional market share. On the one hand, consistently higher quality is generally more expensive to produce. Since, as described in Chapter Two, Japanese firms were relatively less constrained by a concern for current earnings than U.S. firms, they could afford to spend more on quality without increasing the prices they charged. The effect could be to penetrate the U.S. market through "dumping" high quality (because not reflected in component price), thereby evading the problem of price-triggered dumping accusations. On the other hand, quality is built in to the production process. U.S. manufacturers, until the advent of Japanese competition over quality, had made a tacit decision that fast, volume output with component testing, to cover imperfections in the manufacturing process, was more important than high quality. The Japanese instead concentrated on perfecting their production process to deliver higher quality devices. As U.S. firms retool and expand capacity, they have apparently been "tweaking" their production process to meet higher quality standards.[9] It may well be, then, that the Japanese ability to use quality as a penetration strategy will not carry over to the next round of competition.

In sum, the 16K RAM market was the most significant battleground for U.S.

and Japanese IC competition in the late 1970s. As we would expect from the discussion in Chapter Two, the Japanese firms systematically used their controlled domestic market as a secure base from which to gain significant penetration of the U.S. market. Although the 16K RAM was U.S. innovation, and U.S. merchant firms were the first volume producers of the device, Japanese firms used their control over access to this domestic market to prevent U.S. firms from consolidating an initial lead in 16K RAM's into long-term advantage in the Japanese market. Instead, Japanese firms followed their characteristic strategy of exporting from a large-scale production base built in their secured home market, and thereby captured over 40 percent of the U.S. 16K RAM market. Stable availability of capital at home secured the Japanese domestic base and underwrote the ability of Japanese firms to compete on price in the U.S. Market. Thus by exploiting their systemic strengths the Japanese emerged from the 16K RAM battle, at the end of the 1970s, as formidable international competitors at the leading edge of commodity IC memories.

II. Structural Adjustment in an Age of International Competition

Japanese entry into the United States 16K RAM market only strengthened a set of more generic challenges confronting U.S.-based integrated circuit producers in the late 1970s. The fact that Japanese entry occurred in the high-volume memory market, which had historically delivered the margins upon which U.S. merchant firms had in part financed their continued growth, only served to heighten the severe capital constraints which the U.S. industry faced in the late 1970s. These constraints can be broken down into two separate but related strategic areas: (1) financing the expansion of capacity to meet rapid growth in world demand across the range of integrated circuit devices; and (2) financing the development of the next generation of IC products associated with the advent of VLSI (very large scale integration). In the context of rapidly escalating capital equipment and design application costs, Japanese entry exacerbated the cash flow problems which the industry confronted in trying to finance both growth and new product development.

U.S. firms responded to these interrelated market and financial challenges in two ways: politically, and through new market arrangements. The major political response was the formation of the Semiconductor Industry Association, which coordinated intensive lobbying of the United States government. Through political action the industry sought both to sensitize the U.S. government to the nature of the Japanese "threat" and to generate policies that would facilitate the industry's future growth.[10] Responses in the market, although they differed among firms, were all calculated to generate the capital necessary for continued competitive growth and to spread the costs of new product development and market penetration. This was accomplished through a series of cross-licensing and technology-exchange agreements, acquisitions and equity investments, product-development contracts with electronic system manufacturers, integration forward into systems markets by merchant producers, and integration backward into captive production by a variety of systems producers. Each of these new market arrangements between firms helped to facilitate a rapid expansion of capacity for existing products and also to sustain the level of research and development across the industry as a whole. Together, these political and market responses effectively enabled U.S. firms to meet, at least over the short term, the challenges of increased international competition under conditions of rapid market growth.

Cross-Licensing

Cross-licensing, technology exchanges, and less formal second-source arrangements were a major way in which U.S. firms spread the risk of both systems development and market penetration in the late 1970s. For example, by developing and cross-licensing different components of a systems product, U.S. firms were able to spread the risks and share the costs of development and production. U.S. firms also were able to enter systems markets with assured second sources tied together through cross-licensing arrangements. The assurance of supply and support which these actions represented enabled easier market access and more rapid customer acceptance. Moreover, cross-licensing and technology exchanges dispersed technical know-how among the partners and thereby enhanced the technology position of each. The different deals struck during the late 1970s captured different aspects of the opportunities described above. The particular characteristics of each deal depended upon the strengths, needs, and strategies of the partner firms.

The advantages and opportunities of exchange can be best seen in the proliferating deals which centered on the rapidly expanding markets for microprocessors (MPU) and related devices. Market penetration required not only that MPUs be supported with a supply of memory and peripheral chips, which would in effect create an MPU-based systems product, and that true-mask second sources be available. The costliness of developing and adding peripherals and the need for second sources resulted in a number of mask exchanges and cross-licensing agreements during 1977, 1978, and 1979. Major MPU peripheral deals involved the proprietary 8 and 16-bit MPU families of such U.S. firms as Intel, Texas Instruments, Motorola, Rockwell and Zilog.[11] For example, Motorola licensed its 8-bit 6800 MPU to Hitachi in exchange for three controller chips, and has entered into similar exchange agreements with Hitachi, Rockwell, and Thomson-CSF for its 16-bit 68000 MPU. Rockwell reached deals with MOS Technology and Synertek for its 8-bit 6500 family MPU, and Texas Instruments reached deals with AMI and Standard Microsystems for its TMS 9900 MPU. The advantages of such agreements are perhaps best illustrated by the case of a deal between two smaller merchant firms, Zilog and AMD, which was built around Zilog's 16-bit Z8000 MPU. AMD is second-sourcing the Z8000, and has developed three peripheral chips for it; Zilog, in turn, will second-source the three chips, and has developed four additional peripheral chips which AMD will second-source. Through these actions, the total system development costs have been spread and the complete system is second sourced, which will make market penetration easier. Thus, the challenges of high development cost and market entry, which might have overtaxed each firm acting alone, were successfully met through cross-licensing.

Another pattern of cross-licensing involved the exchange of differing proprietary technologies. Intel was a notable participant in this area. For example, Intel licensed the MPU-peripheral architectures of its MSC-48 and UPI-41 families to IBM in exchange for IBM's current bubble memory patents. Intel also exchanged certain 8-bit MPU masks and process technologies with Phillips for charge-transfer device and Locos (local oxidation of silicon) technologies used in MOS VLSI. Similarly, Texas Instruments licensed masks for its 16-bit MPU to AMI in exchange for AMI's proprietary V-MOS technology.[12] These and similar deals broadened the potential markets for product and process technology, spread the cost of technology development, and broadened each firm's technology base.

The participants in the majority of these cross-licensing arrangements were the largest merchant firms (those with IC sales above $100 million in 1979). Unlike smaller firms, these companies had both the productive resources and the complementary proprietary technologies necessary to strike mutually beneficial bargains. For them, opportunities for growth lay in all the major markets -- especially the computer, industrial, and consumer markets -- served by the range of their IC products. Through cross-licensing, they could take advantage of each other's competitive strengths to build market position and simultaneously reduce the risks and costs of product development. Cross-licensing and related arrangements thereby served to help meet the problems of rapid market growth and technology development which dominated the industry's agenda in the late 1970s.

Acquisitions

Acquisitions and major equity purchases of merchant U.S. semiconductor firms were another competitive response to the challenges of rapid growth.[13] For the smaller U.S. firm, faced with costly problems of growth, development, and competition, acquisition often delivered a number of advantages. First, it provided an infusion of capital to meet the demanding requirements of capacity expansion and continued technology development. It also held out the promise of future access to cheap debt capital for continued expansion. Second, acquisition often meant access to new geographic and product markets through the marketing resources and systems products of the parent. Third, acquisition also offered access to the parent firm's technological and production resources, which meant the ability to acquire technology and to move forward into production of more complex systems devices. In many cases, of course, acquisition held out the notable long-run disadvantage of the loss of corporate autonomy or identity. For the parent firm, however, acquisition offered several obvious advantages. First, for foreign electronics firms acquisition meant instant access to the U.S. market in both semiconductors and electronic systems. Equally important, acquisition meant access to the world's most advanced semiconductor technology. Finally, for original equipment manufacturer's (OEM) integrating backward into semiconductors, acquisition provided a cheap, rapid way of "installing" a captive semiconductor division. The different acquisitions and equity investments listed in Table 4 (Chapter One) each express different aspects of the above advantages, and it will be instructive to examine some particular cases.

The AMD-Siemens linkage is an ideal case of a mutually beneficial competitive response to market challenges. It increased AMD's access to cheaper capital and gave AMD entry to some of Siemens' markets. This kind of mutually advantageous arrangement is also indicated in the Phillips-Signetics merger, and in the United Technologies-Mostek and Schlumberger-Fairchild acquisitions. All of these semiconductor firms are large producers who have the financial muscle for capacity expansion and product development. These firms have, moreover, broadened their systems capability and enhanced their opportunities in the parent's markets.

Competitive enhancement for the parent firm similar to the AMD-Siemens deal can be seen in the equity acquisitions by Bosch and VDO to feed their automotive systems requirements, by Lucas to meet its automotive and aerospace market needs, and by Northern Telecom for its telecommunication needs. In each case, rapidly expanding market demand for advanced electronic systems required the acquisition of the advanced LSI capabilities upon which those systems rest. The acquired firms in these cases -- AMI, Solid State Scientific, Siliconix, and Intersil -- were each significantly smaller firms than AMD. The effect has been to stabilize their growth by infusing capital and providing systems markets for their products. With the possible exception of AMI, these and similar _smaller_ firms will coalesce around the systems market segments served by their parent companies. In this way, competitive adjustment has been achieved by tying the more limited capacities of the smaller firms to the IC requirements of particular fast-growing final market segments.

A slightly different competitive response can be seen in the complete acquisitions of smaller firms by OEM's like Honeywell, GTE, and Commodore International. Here, the small acquired firms have mostly lost their independent character and have become essentially captive component divisions of the parent firm (although Synertek and SEMI still sell MOS ICs on the open market -- a function of the advanced LSI MOS needs they meet for their parents). The parent firms have thereby developed an assured supply and advanced technology base to meet the demands of the expanding final markets they serve. The future implications of such backward integration (here, through acquisition) will be dealt with in the upcoming section on vertical integration.

In almost all of the acquisitions, then, the acquiring firm acted to acquire advanced technology, to establish market position, or to ensure supply for their own needs. For the larger acquired firms, their "parents" provided the capital needed for expansion and development, and often provided new or expanded market opportunities as well. For the smaller "merchant" firms, acquisition meant the ability to consolidate their resources around particular market opportunities for growth. Finally, the independence of some smaller firms was sacrificed to the needs of their parents for captive production in expanding electronics end-markets.

Technology Development Contracts

The infusion of IC technology into rapidly growing new or changing markets required significant development and applications expenditures. The costs of such development were sometimes picked up through technology development contracts, by the equipment manufacture whose specific needs had to be met. The competitive benefits to U.S. IC firms were obvious: they developed new technologies at minimal cost to themselves, and often gained market access for their resulting products. While such contracts were given in most major market segments, the notable example for its size and impact was the series of development contracts given by GM to develop IC-based automotive electronics systems.[14] The automotive operating environment and range of applications posed flexibility and reliability requirements seldom demanded of IC systems. Moreover, GM imposed quality-failure rate targets "literally orders of magnitude lower from one generally associated with . . . large-scale integrated circuits." The result for IC vendors who participated in GM's program (and similar programs by Ford and others) was a significant leap in product and process development technology, and eventually a share in GM's huge procurement program (for the winners). That program now finds sources of circuits worldwide to support GM's overseas activity, and for GM's IC vendors like Fairchild, Hitachi, Motorola, National, Signetics, and Texas Instruments, it represents significant new market demand. As one indication, Table 12 gives the percent of existing world capacity (at the end of 1979) that GM-Delco will consume in 1981 for selected ICs. Note, of course, that the major participants in this rapidly growing market are the largest merchant U.S. producers and the larger foreign IC firms.

Table 12

GM/DELCO IC CONSUMPTION
(by device)

Device	% World Consumption
8k PROM	56%
MOS ROM	17%
Low Power Schottky	6%
MOS Logic	10%
Data Conversion	40%

SOURCE: Rosen Electronics Letter, July 15, 1980, p. 143.

Vertical Integration

Perhaps the most significant response by U.S. firms to the challenges of market growth in the late 1970s was the continued forward integration into systems by the largest "merchant" U.S. firms and the exceptionally rapid backward integration into semiconductor production by a wide range of OEMs.

Backward Integration. From 1977 through 1980 there was a literal explosion of backward integration by OEMs into semiconductor production, and the pace is accelerating.[15] By 1980, at least 45 major OEMs at some 80 locations had established captive semiconductor operations ranging from R&D labs to full production lines. These companies spanned all of the major semiconductor markets: computers, data-processing, telecommunications, industrial, consumer, and military. There were three major competitive reasons for the growth in backward integration. First, as microelectronic products increasingly infiltrated new systems markets, OEMs integrated backward to insure themselves a competitive position in those markets. Second, the serious supply shortages in the merchant market during the late 1970s forced OEMs into captive production to ensure supply for their needs and to supplement purchased inventories. Third, most OEMs have relatively low-volume custom circuit requirements, which merchant firms have been unwilling to meet. Moreover, even where custom volumes have been large enough to attract merchant production capacity, captive production has remained an attractive secondary source of supply. A representative list of large-sized captive and mostly captive suppliers is given in Table 13. The large number of U.S. firms now engaged in or entering into integrated circuit design or production, including some of the United States' largest manufacturing enterprises, suggests a broadening of the technological base in the United States which should enhance the pace of both innovation and diffusion in microelectronics.

It is important to note that the growth in captive facilities was made possible in part by the emergence in the later 1970s of a sophisticated infrastructure of independent firms -- manufacturers of materials and equipment for testing and production, and suppliers of analysis, consulting, and design services to both captive and merchant semiconductor producers. This infrastructure had developed during the 1970s to support merchant firms, but its capacities were ideally suited to the needs of backwardly integrating OEMs. The flexibility and capacities of this segment of the U.S. industry are a major competitive strength. Through a combination of meeting user requirements and carrying on independent research into semiconductor manufacturing processes, the equipment producers have become increasingly important to the technical progress and competitive position of the U.S. integrated circuit industry.

Forward Integration. The forward integration of the largest merchant U.S. semiconductor firms during the LSI period (described in Chapter One) continued apace in the late 1970s. As development and design costs rose with the complexity

Table 13

U.S. CAPTIVE SUPPLIERS

Company	R&D Lab	Prototype Lab	Pilot Production	Full Production
Aerojet Electro Systems	X			
Amdahl Corporation	X	X		
Ampex Corporation				X
Bell Telephone Labs				
Boeing Company	X	X		
Burroughs	X	X	X	X
Chrysler Corp.	X	X		
Control Data Corporation	X	X	X	X
Cutler-Hammer/Eaton	x			
Data General	X	X	X	X
Datel Systems		x		
Delco Electronics Divivision	X	X	X	X
Digital Equipment Corp.				
Eastman Kodak	X	X	X	X
E-Systems, Inc.	X	X		
Essex Group, Inc.				X
Fluke Auto. Sys. Division				
Ford Aerospace Communications	X			
Foxboro Company				
Four-Phase System, Inc.	X	X		
General Dynamics			X	
General Electric				
SSAO	X	X	X	
Corporate R & D	X	X		
Aerospace Electronics Systems	X	X	X	X
Gould, Inc.	X	X		
GTE Laboratories	X	X	X	
Hewlett-Packard				
General Systems Division				
Santa Clara Division				
Microwave				
H.P. Labs				
Optoelectronics				
Stanford Park Division				
Instrument Division				
Desktop Computer Division				
Instrument Division				
Handheld Calculator Division				

Table 13 (continued)

Company	R&D Lab	Prototype Lab	Pilot Production	Full Production
Honeywell				
Solid State Electronics Center	X	X	X	
SSEC Center				X
IBM				
Corporate	X			
General Systems Division		X		
Data Systems Division				
General Technology Division				
System Development Division	X	X		
Data Products Division			X	X
General Systems Division			X	X
Federal Systems Division			X	X
Lockheed Missiles and Space	X	X	X	
Magnavox	X		X	
Martin Marietta Aerospace	X	X		
McDonnell-Douglas				
Astronautics	X			
Micro-Rel	X	X		
NCR				
Northern Telecom				
Northrop	X			
Rosemount	X			
Sandia Labs	X	X	X	
Sperry				
Storage Technology Corp.				X
Microtechnology	X	X	X	
Stromberg-Carlson	X	X	X	
Tektronix	X	X	X	X
Western Electric				
Teletype Corp.		X	X	X
Westinghouse	X	X	X	X
Friendship Solid State Research	X			
Xerox	X	X	X	
PARC	X	X		

SOURCE: ICE, STATUS, 1980, p. 59-61.

of IC devices, these firms moved forward into systems production to recapture the higher value-added which systems represented. The move forward was also aimed at meeting the applications needs of users in systems markets, and thereby served to enhance and establish positions in expanding markets. Earlier sections of this chapter have described some of the move forward in terms of cross-licensing arrangements, acquisitions, and development contracts. In addition, the largest firms integrated forward by establishing systems subsidiaries and through forward mergers.

Once again, the movements forward by different firms spanned the major markets for semiconductor devices. Texas Instruments continued to expand into a broad range of consumer systems markets, as did Fairchild (electronics games) and Motorola (automotive entertainment) in discrete consumer product segments. Motorola continued to expand its telecommunications capability, notably through acquisitions of two small modem (communication chip) producers, Codex and Universal Data Systems. National moved further forward into plug compatible machines (PCM) through merger with its formerly independent marketer, Itel. All of the major MPU manufacturers moved forward into microcomputer systems, into MPU-based industrial control systems, and toward distributed processing systems. These moves included further refinement of microprocessor development systems and entry into software support, notably by Texas Instruments, Motorola, and Intel, in the form of ROM-based "firmware." The notable purchase in the software-distributed processing area was Intel's acquisition of MRI Systems Corp., a Texas vendor of data base management software.[16]

The Impact of Integration

In the late 1970s, vertical integration both backward and forward expressed most dramatically the impact of rapid growth of the different markets served by IC-based electronic system products. The fact that moves toward vertical integration are being pulled so dramatically by the market suggests that the most recent wave of integration is different in kind from those that may have preceded it. For OEMs, captive capacity is no longer merely the source of potential competitive advantage. Rather, because it serves the strategic needs described above (under "backward integration"), it appears to be absolutely essential merely to remain internationally competitive. For large IC firms, integration forward is no longer merely a potentially lucrative market opportunity. Rather, it appears to be the primary way that enough invested value can be recaptured to underwrite continued, internationally competitive growth and development at the levels achieved in the past.

Market Outcomes and Industrial Restructuring

The market challenges and competitive responses in the U.S. IC industry during the late 1970s were dominated by the fact of rapid growth throughout the spectrum of markets served by IC firms. Rapidly expanding markets helped make possible Japanese penetration, stimulated captive production, and required capacity expansion. In conjunction with rapidly escalating development and applications costs, rapid growth was the main impetus behind the patterns of cross-licensing, acquisition, vertical integration, competition, and consequent market concentration described above. Moreover, the requirements of rapid growth also spurred a proliferating and flexible infrastructure of independent semiconductor firms providing materials, production and test equipment, and services. Taken as a whole, the actions described in this section constitute a process of ongoing industrial adjustment to increased international competition under conditions of rapid market growth. This outcome, in terms of world IC production and market share, is summarized in Tables 14 and 15. As these figures suggest, the decline in U.S. (and merchant) world market share between 1974 and 1978 was arrested during 1978-1980 by the flexible and manifold responses detailed in Section I. Total U.S. world market share, both merchant and captive, has stabilized since 1980 and may even have risen.

Table 14

WORLD IC PRODUCTION
(millions of dollars)

Producing Region	1978[a]	1979[b]	1980[c]	1981[d]
U.S.				
IC Merchant	3,238	4,071	6,360	7,000
IC Captive	1,344	2,010	2,695	3,050
IC Total U.S.	4,582	6,681	9,055	10,050
Western Europe				
IC TOTAL	453	600	710	765
Japan				
IC Total	1,195	1,750	2,580	2,970
Rest of World				
IC Total	782	675	740	835
Total ICs	7,012	9,706	13,085	14,620

SOURCE:
a) ICE, STATUS 1980, p. 4.
b) ICE, STATUS 1981, p. 2.
c) Figures after November 1980 estimated
d) Estimated for year

Table 15

WORLD IC MARKET SHARE, U.S. and JAPAN
(percent)

Country	1978	1979	1980[a]	1981[b]
U.S.				
Total	68%	71%	72%	73%
Merchant	48%	50%	49%	50%
Captive	20%	21%	23%	23%
Japan				
Total	18%	16%	16%	15%

SOURCE: Based on Table 14; percentages have been rounded.

[a] estimated
[b] projected

What is concealed by the aggregate figures in Tables 14 and 15 is the degree to which the industry's adjustment at the end of the 1970s has altered the industry's organization. As Chapter One has demonstrated, expanding markets, competitive challenges, company responses, and market outcomes have historically interacted in different periods to restructure the semiconductor industry. Indeed, what the process of adjustment described in this section suggests is an emergent competitive restructuring of the U.S. industry. This emerging structure is best understood as a process of market segmentation.

By segmentation, we mean the emergence of large and rapidly growing market segments for electronics systems within the overall markets for computers and data processing, telecommunications, and industrial, consumer, automotive, and military applications; each segment is served primarily by a number of the largest merchant firms who will overlap from segment to segment, and secondarily by a few of the smaller firms (among which, from segment to segment, there will be little or no overlap). Because markets are growing so rapidly and are producing such varied and costly demands on IC technology, however, a merchant "components" sector cannot economically serve all markets and meet all demands. Therefore, coexisting with merchant firms will be significant captive production firms, which fill the segment gaps inadequately served by merchant production. Thus the pattern of OEM backward integration described above is, in fact, an expression of the occurrence of market segmentation. Similarly, the patterns of cross-licensing, acquisition, and forward integration have positioned the participating firms to take advantage of growth opportunities in different market segments.

This process of segmentation is likely to produce discrete tiers of merchant firms differentiated on the basis of size, growth, profitability, systems capability, and the degree of their formal ties to OEMs. The largest merchant firm will expand rapdily, become more and more like systems houses, and be very profitable. Since the systems required to serve different segments will overlap, these firms will appear to be relatively full-line systems houses. Comparatively smaller firms are likely to be locked into one or two major market segments where they will be significant participants, but their growth will be slower and they will be less profitable. The smallest firms are likely to coalesce as secondary suppliers around the distinct market segments served by the largest merchant firms or served by OEM captive production. However, these smallest firms will also serve non-captive market segments that demand low-volume custom chips.

Market segmentation and its generation of growth opportunities within market niches is likely to foster a spate of new merchant entries. Since capital gains taxes were relaxed in 1978, venture capital has been flowing at an increasing rate into start-ups in the different sectors of the U.S. economy. Venture capital financed an estimated $250 million in new enterprises in 1980, up from just $20 million in 1975.[17] A share of that capital has indeed found its way into the semiconductor industry. The explosive growth potential of IC markets and the new availability of venture capital have attracted entrepreneurs away from established IC firms into new ventures.[18] For example, five engineers left Intel in January 1981 to start Seeq Inc., which will compete in Intel's markets. National Semiconductor lost four top employees in July 1981 to a new venture that will produce linear ICs for the instrumentation and telecommunications markets.

New ventures are also being fostered to meet some OEM demand for custom chips, because backward integration to produce low-volume custom chips in a range of new market segments is likely to be too costly for those OEMs. Such entry could well take the form of the "silicon foundry," which would run off a batch of chips based on custom masks designed and delivered by the customer. As the infrastructure of semiconductor service firms proliferates, the ability to design and produce custom masks will also grow. At least one silicon foundry venture was started in 1980, VLSI Technology. To the extent that the foundry proves economical, the larger merchant IC firms are also likely to open divisions that perform foundry services. If that occurs, the largest firms will profit by serving custom market segments they now ignore.

The restructuring of the U.S. industry in the ways outlined above may be seen as the obvious result of rapid market growth in a situation where the industry's firms are disparately positioned, on the basis of capacities, to capitalize on market opportunities. In that sense, the projected changes in the U.S. industry represent an intensification of structural tendencies not fully realized during adjustment throughout the era of LSI in the 1970s. What is fundamentally new, however, is the presence of Japanese competitors well positioned to challenge U.S.

firms across a range of market segments. Benefits from responding to growing market opportunities that used to redound almost as a matter of course to unchallenged U.S.-based firms may very well be denied them by Japanese competitors. It is to these issues that we now turn.

III. Structure and Strategy in International Trade

By 1980 the Japanese integrated circuit industry had arrived as a market force in international competition. American industry, however, has by no means lost is own market momentum. While Japanese firms together have captured more than 40 percent of the world 16K RAM market, over the entire range of integrated circuit production U.S. firms have managed to absorb that loss and sustain their overall world market-share position. Indeed, were the full extent of U.S. captive production known, it is likely that the percent of world production accounted for by U.S.-based firms has actually increased.

Some ominous clouds, nonetheless, have appeared on the U.S. horizon. Japanese firms have led their U.S. competitors in more quickly introducing and moving into production the latest generation of random access memories -- the 64K RAM. As noted in Chapter Two, the Japanese have proved quite competent as market followers but as yet have failed to lead American firms in new product and market development. For this reason, early Japanese entry into the 64K RAM market caught many observers by surprise. This attempt to establish an early market position, however, remains as yet no more than an attempt; sustaining a leadership position will be fraught with difficulties.

Both Japanese and American firms appear to have prepared for a major market battle in the 64K RAM. The ten largest Japanese firms spent more than $500 million in 1979 and more than $775 million in 1980 on semiconductor plant and equipment -- that is, between 17 and 18 percent of sales. Having learned their lesson in the 16K RAM market, where a failure to keep investment levels high during the 1975 recession led to a loss of market shares in the period 1978-1980, the ten largest U.S. merchant producers have more than matched the Japanese in adding new capacity. As a group, these ten producers spent more than $910 million in 1979 and more than $1.2 billion in 1980, or more than 20 percent of sales during each of the two years. Given the relatively depressed conditions of IC sales since the fourth quarter of 1980, the willingness of the U.S. industry to spend during the current recession suggests a heightened awareness of the role which capacity and scale play in Japanese strategy.

Although the leading U.S. merchants are no strangers to the strategy of gaining a market share position on the basis of scale economies and learning curve efficiencies, historically it has been process innovation and new product development that have supported U.S. international competitiveness. In this respect, even amidst the boom in capital investment, U.S. firms appear not to have sacrificed research and development; as a group, they have maintained research and development expenditures at around 10 percent of sales. Indeed, it appears that the early Japanese position in the 64K RAM market could be made vulnerable by an innovative effort on the part of several of leading U.S. producers.

One of the reasons for the early Japanese lead in the introduction and production of 64K RAMs was that they adopted a relatively conventional approach in their design, enabling them to quickly turn their experience in the 16K RAM design towards the task of producing the 64K device. Early U.S. designs, first announced by the leading U.S. "captive" producers (IBM in 1978 and Bell Labs in 1979), called for the incorporation of "redundancy" as "fault tolerance" in the layout of the 64K device. As a matter of design, a chip incorporating "redundancy" has an extra set of spare cell rows and columns. After wafer fabrication and processing, computer-controlled testing equipment can be used to locate defective cells in the individual chips on each wafer and permanently inactivate them. The extra set of spare cells is then used, and the otherwise defective chip can thereby be made to function properly. The use of redundancy, then, can dramatically boost yields -- the number of usable chips per wafer manufactured -- because the design and process allows the additional cells to be substituted for the defective ones to create a functional device. Thus, the use of a redundant design and the associated improvement in yields should lead to lower unit costs and also should reduce the investment in plant and equipment required to meet the volume demand expected to emerge for the 64K RAM device.

Although the first 64K RAM device offered in limited sample quantities by U.S. merchant firms (Texas Instruments and Motorola) did not incorporate the use of redundancy, considerable momentum behind the redundancy design has been generated with the announcement by Intel late in 1980 of its redundancy device; following Intel, both Mostek and Inmos have announced a commitment to the use of redundancy. The Japanese firms, with the exception of Fijitsu, appear not to have anticipated the need for redundancy prior to production of a 256K device. This may reflect an expectation that yields on their conventional device will, in combination with a massive increase in production capacity, leave them cost-competitive with U.S. firms in any event.

The outcome of the 64K RAM market competition between Japanese and American firms is still uncertain. Nonetheless, the competition to date illuminates the relative strengths and weaknesses of the two industries. It appears that the early leadership of Japanese firms has been premised on a build-up of 64K RAM capacity for "captive" demand in the domestic market, which would then enable them, through price competition, to gain a dominant international merchant market position. Indeed, while most industry analysts did not expect 64K RAM prices to fall below $10 per chip until 1982, it appears that Japanese firms have already begun to quote a $4 price in an effort to pre-empt American market competition.

It thus appears that in the coming battle in the 64K RAM market (as in the 16K RAM before it) the Japanese, by applying their unique production strengths and domestic market power, will become a particular kind of competitor in the international merchant market. The stable availability of debt capital underwrites their growth, development, and ability to compete abroad. Rationalization and oligopolization of the domestic market among the major Japanese firms help to create a stable environment and may be used instrumentally to achieve scale economics and, by freeing individual firm resources, to encourage production for export. Control over access to the domestic market limits the ability of U.S. firms to turn the competitive advantages from product innovation and market position abroad into long-term market share in Japan. Ongoing government promotion of cooperative R&D further compensates the Japanese firms for their relative international weaknesses in technological innovation. In short, the large, vertically integrated Japanese electronic firms use their controlled domestic market as a stable, high volume production base from which to achieve penetration and potential competitive domination of foreign markets. Unlike their U.S. merchant competitors, the strength of the Japanese semiconductor firms lies in a production strategy rather than in innovation strategy.

In its traditional role of promoter, following MITI's basic strategy of creating comparative advantage in the knowledge-intensive industries, the Japanese government appears intent on further assisting the international competitiveness of its IC-electronics firms.[19] Thus, for example, the major IC-computer firms, with MITI funding, have created the Electronics Computer Basic Technology Development Association to continue the computer development efforts that emerged from the VLSI program. The Association's major focus over the short term is to overcome Japan's seriously uncompetitive position in computer software development. Table 16 gives a rough indication of ongoing major Japanese government support to the Japanese electronics industry.

Such massive support will coincide nicely with the Japanese firms' long-term strategy in integrated circuit and system markets. Indeed, the current ability of the Japanese to be competitive in international RAM markets apparently presages an attempt to dominate a broad range of both commodity IC and electronics systems markets. RAMs are among the few large volume products that can provide Japanese firms with the manufacturing and technological know-how to continue to move forward along the path of innovation established by U.S. firms.[20]

In semiconductors, however, U.S. firms still dominate MPU, peripheral, logic circuit, and custom circuit development and production. The Japanese firms, in turn, are aiming for the lucrative computer and telecommunication markets. Indeed, since the end of the 1970s, Fujitsu has developed joint venture links with TRW and Sumers. These give Fujitsu a strong new toehold for distributing and improving its computer system in both the U.S. and European markets. The Japanese are also strong players in the growing automotive electronics markets.

The long-range competitiveness of the Japanese industry in commodity IC and systems production may be further enhanced by an unwillingness to license proprietary production technologies that emerge from either government-coordinated or individual-firm R&D. Indeed, it appears, either as a matter of MITI policy or industry choice, that U.S. firms are being denied access to proprietary

Table 16

MAJOR JAPANESE GOVERNMENT SUPPORT TO INFORMATION INDUSTRY

Type of Support	Years	Million $
Hardware		
Pattern Information Process	1971-1980	104
3.75 Series Computer	1972-1970	290
Peripheral Development		
IC Development	1973-1974	17
VLSI Development	1970-1979	139
Base Tech. for New Era Comp.	1970-1979	(350)
Scientific Processor (Super)	1981-1988	112
5th Generation Computer System (In Planning)	1981-1990	In Planning (500M Pro)
Opto Elec. Applied Measurement & Control	1979-1986	86
Opto-IC Development	1981-1991	In Planning
Software		
Software Module Development	1973-1975	14
Software Product Technology	1976-1981	32
IPA Agency (Prgrm. Dev.)	1971-1980	52
Software Mtce. Tech. Dev.	1981-1985	24
Loans		
Japan Dev. Bk to IECC	1971-1980	1,900
Bank Loans to Software Co.	1971-1980	487

SOURCE: IECC Computer Note.

production technologies that emerged from the VLSI project and are being made available to Japanese firms.[21] This should not be surprising, since the source of Japanese competitive advantage lies in their production strategy; it suggests, however, that the Japanese are determined to remain formidable international competitors by controlling access to the fruits of "controlled competition" as well as to the market.

By contrast, the U.S. merchant firms against which the Japanese industry has taken aim continue to generate a technological and competitive dynamism unique to the American industrial structure. Dynamic technological advance has underwritten the international competitiveness of the American industry. In this, the merchant firms have played a critical role both as innovators and as diffusers, with no stake in keeping from the market the technological advances in which they have invested. Indeed, the merchant's ability to innovate and fuel the process of diffusion has depended upon their achieving as wide a market for their new products as possible. Commodity positions in a high-volume market have enabled them to finance the risks of new product development and thereby to act as an independent catalyst to the process of technological innovation across the electronics industry as a whole.

The immediate Japanese threat is to this merchant sector of the U.S. industry. By bringing their high-volume strengths to bear in merchant competition, Japanese firms could come to dominate U.S. microelectronic commodity markets to an extent that would deny U.S. firms the margins that have historically underwritten their capacity to create new products and develop new markets. Thus, over the long-term, significant Japanese domination of merchant commodity markets -- if it occurs -- could rob the U.S. electronics industry of the competitive dynamism which has been its hallmark. The pace and character of innovation and diffusion throughout the U.S. electronics industry could be slowed. The Japanese could, in other words, come to dominate systems markets over the very long term.

We do not mean to overstate the nature of the competitive challenge from Japan. These threats to the long-run development of the U.S. industry and economy are no more than possibilities at present. Nor should U.S. policy be premised directly on such possibilities. The one certainty is that the Japanese will continue to develop an internationally competitive IC-electronics industry to underpin the knowledge-intensive development of their own economy. How U.S. policy should respond to Japanese ambitions is the subject of the next and final chapter.

Chapter Four

THE STRUGGLE FOR ADVANTAGE IN INTERNATIONAL ELECTRONICS COMPETITION

The semiconductor industry is at the heart of the transformation of industrial life being produced by information-processing technology. Its application to data processing, automated production, robotics, communications, and military systems is changing the goods we use, the way we make those products, and the means by which we communicate with each other. In the trade among the advanced countries, competitive position is gained by product differentiation and the management of sophisticated production systems, both of which will be shaped by the possibilities offered by integrated circuits. Consequently, in our view, the relative strength of the several advanced industrial countries in the next few decades will be significantly affected by differing national capacities to develop and apply these electronic component technologies.

The policy task is to reconcile the desire of the United States to maintain its position in the forefront of this industry with Japanese and European desires to situate their industries so they may also ride the wave of electronics into the future. The story told here of marketplace competition is also a tale of conflict between nations over the role of government in promoting and shaping growth sectors. In the 1980s trade debates about government policies of procurement and promotion, rather than arguments about tariffs and quotas, will be central. The integrated circuit case, where government policies are so important, may prove to be a prototype for the trade conflicts of the next decade. The real danger is that each nation's pursuit of its own advantage will fragment this worldwide industry into a series of national markets insulated by policies of government procurement and subsidies. Since the most pressing problem for the United States has been the surging Japanese industry, our discussion focuses on Japan. However, it must be recognized that American-Japanese conflicts cannot be resolved without attention to the European position.

I. The Problem Reviewed

This section summarizes the argument developed in the first three chapters and depends on the evidence introduced there. We shall not introduce new evidence in this chapter, but later on we shall suggest tests of the arguments presented earlier when we consider the policy implications of our analysis.

American electronics producers dominated world markets for the semiconductor components -- from which advanced electronic systems are built -- from the time of the industry's inception until 1979, when Japanese producers captured 42 percent of the American market for 16K RAMS (sixteen-thousand-bit random access memory devices). That surge signaled the beginning of a challenge to American pre-eminence in advanced electronics. Success with a sophisticated product in an advanced technology industry underscored the economic and technological competitiveness of the Japanese electronics industry. At the end of the Second World War Japan still depended heavily on agricultural production, and the Japanese manufactured goods sold in world markets were primarily labor-intensive. The government, specifically the Ministry of International Trade and Industry, sought to advance the Japanese position in the world economy and took concerted action to promote rapid industrial development and the expansion of capital-intensive production. Domestic markets were insulated from foreign direct investment and imports. Foreign firms sold their technology to Japanese companies because they were not permitted to enter the Japanese market.

Importantly, the government chose to sponsor those sectors in which rising Japanese incomes would mean an expanding market, and in which Japanese firms competing for home demand would gain the economies of scale they needed in order to export. By the middle 1970s Japanese firms had become a force in international markets for steel, ships, autos, and consumer electronics. The first shift away from labor-intensive to capital-intensive production was achieved.

Today the Japanese government, as a matter of national economic policy, is actively promoting the development of knowledge-intensive industries such as the industry that produces integrated circuits and the systems built from those circuits, which include computers, telecomunications, and automated production equipment. The direct influence of the government in industrial affairs has dwindled, and intergovernmental rivalries -- such as that between MITI and NTT -- are important to understanding both the formulation and the implementation of policy. Nonetheless, the high-growth techniques first applied in the 1950s and 1960s to industrial catch-up are now being used in the 1970s and 1980s to create an advanced Japanese position in markets for electronics. Japanese government policies and private industrial arrangements create advantages in international competition for Japanese companies that place otherwise competitive American firms under intense market pressure. Those advantages encourage longer-term corporate planning horizons by lifting constraints that force a shorter-term perspective on American firms. More concretely, they permit Japanese firms distinct production strategies not open to most American companies. An internationally competitive Japanese electronics industry has been built up, like other priority industries before it, with active government assistance; and within protected markets, direct government aid has gone not only to promote the advance of integrated circuit technology, but to support the development of the final systems, such as computers and telecommunications, in which semiconductors are used.

Trade policy has been as important as direct promotion in the evolution of the Japanese industry. The main threat of Japanese policy over the years, we have argued, has been to manipulate access to the domestic market as a means of neutralizing the strength of American firms. At least until 1978, the government forced American firms to sell their patents and know-how to Japanese firms rather than allowing them to sell and produce in Japan. Although many of the formal restrictions on sales and direct investment in Japan by foreign companies are being eliminated, access to the Japanese market remains very difficult for foreign producers. The inter-company ties built up during years of formally closed markets do not end suddenly because the government announces elements of a more open policy. For example, the market for integrated circuits is dominated by six large captive producers, each is part of an integrated electronics systems house that incorporates integrated circuits into its final products. The final systems product speciality of each electronics firm is reflected in the type of semiconductor devices it produces, which is not surprising. Yet on the average less than a quarter of each firm's production is for its own use; because these firms account for over 70 percent of production and 60 percent of consumption, there is extensive trade between them. The evidence in Chapter Two suggests that the extensive trade between the major firms represents a pattern of convenient specialization which more readily permits each company the volumes it needs to achieve competitive costs in some products. Since the major producers are integrated electronics manufacturers, they are also in a position to subsidize semiconductor development and production capacity with income from the final products.

Such structured markets have been seen before in other Japanese industries.

While competition in Japan is real and intense, it also is controlled or structured to assure conditions for the growth of the electronics industry as a whole. These arrangements assure more stable demand and permit capacity to be expanded more rapidly than would be possible in an entirely open market. Each Japanese firm -- the evidence in Chapters Two and Three suggests -- has been, until recently, able to expand capacity and innovate in production techniques because they could follow technological developments abroad and sell into a closed home market. These production-oriented strategies in commodity products were facilitated by the substantial financial resources that their size and extensive use of debt provided.

Even in an industry evolving as rapidly as electronics, Japanese strategies have at least until now hinged on finding the efficiencies and advantages that become possible when products stabilize and price competition proves essential. Japanese firms are not the only electronic component companies that have adopted a strategy of following the technological and market leaders by entering production in force and selling into already established market segments. Some American firms have also been technological followers, or commodity sellers hovering closely behind the technological leaders. The Japanese firms seem to have been a special type of follower, however. The evidence suggests that until very recently they did not compete to establish any of their own products as industry standards; by saving themselves years of heavy investment in development, they were able to concentrate on production refinements. Now they are on a par with American companies in many technologies, and have entered in force the race toward very large scale integrated memory curcuits (VSLI). Although the technical advance in memory circuits remains extraordinary, that market segment is now established and open to volume production. By contrast, the Japanese have not yet established their own proprietary microprocessor designs as industry standards, and this is a segment where rapid adjustment to market needs is more important. In essence, the Japanese have tended to wait until a clear market emerges and then entered volume production. This is a production bias in Japanese strategies which requires predictable demand and easily available capital. The scale of these Japanese firms and the arrangements of the Japanese financial system assure the finance. A set of integrated companies, each with a captive internal market and collectively engaged in convenient specialization, creates the structural conditions for the stable demand that production strategies require. Demand is all the more stable if foreign -- chiefly American -- penetration into domestic markets is limited.

A pattern of import substitution, originally forced by policy, apparently still continues. There are several explanations for this. The first is that when the Japanese begin to produce a product -- any product -- they immediately have a production advantage over American producers. The economies of scale and learning-curve that characterize the electronics industry make such an explanation implausible. A second explanation -- for which there is no direct evidence -- is that the Japanese have mastered manufacturing techniques which assure significantly higher yields than are being achieved in the United States, and which therefore give them dramatically lower costs. A third explanation is that American companies do not pursue an advantage in the Japanese market, an argument seemingly belied by the aggressive expansion of American-controlled multinational semiconductor companies around the world.

The fourth explanation -- and the one argued here -- is that the secure position of Japanese firms in their home market has historically been the result of a clear and forceful government policy of restricting access to domestic markets. That position is now maintained by the pattern of inter-company specialization noted above. In our view, the Japanese could not have played this production game so effectively if their home markets were truly open. To elaborate the consequences these Japanese arrangements have had for the American electronics industry, we must consider the workings of the American semiconductor sector. Competition in the American industry has centered on continuous product innovation and on the constant diffusion of semiconductors into new markets. Each new generation of technology has rapidly undermined the production advantages gained in the standard circuits of the previous generation. The structure of the American semiconductor industry has encouraged competition by diffusion and innovation of new products, rather than simply by the reduction of production costs in existing goods.

That structure consists of a few giant integrated firms, a number of smaller integrated systems firms, and a vibrant merchant sector. In the United States, in sharp contrast with Japan, the largest giant integrated firms -- ATT and IBM -- by court decree and by corporate choice, have not been sellers of semiconductor components to other users. The market position of the American giants is therefore fundamentally different from that of the integrated Japanese firms. If ATT was allowed to sell on the merchant component markets, then the situations would be parallel. As it is, Japanese firms, through cross-subsidization can use their privileged position as telecommunications suppliers to gain special advantages in commercial semiconductor markets.

It is important, then, that ATT and IBM are not merchants who sell their products to others; they enter the merchant marketplace only to buy in order to supplement their captive production. Because they are not sellers in this 'merchant' market, they tend to diffuse their technology, by development contracts and the exchange of patents and know-how with the smaller producers. The giants are such large producers that they can capture internally adequate benefits from a broadly based research program. As a result, they provide the industry at large with the "public good" of basic research. In part because the giant producers do not use their production muscle in the merchant sector, competition in integrated circuit companies has been in the area of product innovation and diffusion. The merchant sector of the market, firms whose primary business is the manufacture and sale of component products to systems users, has been a crucial prod to competition in all electronics goods. Electronic systems producers depend on semiconductor companies to gain advantage in their final markets, whereas component producers depend on systems customers to achieve the volumes that justify their investment in product development and capacity expansion. The relative advantage in world competition of these semiconductors merchants lies in product innovation and the development of new markets. The American industry, and the merchant sector in particular, has had a relative advantage in "making" new markets by innovating in applications and by advancing the product technology; but they face an intense challenge from the Japanese in the volume production of commodity products. A loss of the volume markets, where Japanese advantages weigh most heavily, might prevent the American firms from using their strengths in entrepreneurial innovation.

It is here that the special policy and market arrangements of the Japanese pose the most serious problem. The Japanese companies have displayed remarkable technological and marketing prowess, but the arrangements in their domestic market (noted above and discussed in Chapters Two and Three) have given them important advantages when competing in commodity semiconductor products in the United States market. As long as the Japanese market is closed off from outside competition, the terms of competition in world markets are biased toward Japanese strengths and against American strengths. There are four main reasons for this. First, the Japanese producers are ultimately not simply merchants of semiconductor products, but competitors in a range of final systems that depend on integrated circuits. Second, individual firms in the insulated and parcelled-out market will face more stable patterns of demand than they would if there were foreign competitors or less domestic specialization. This stable demand permits more rapid expansion of capacity and presumably also a greater automation of production lines. Third, any excess capacity that results from an overestimation of the domestic market can be directed toward export markets. If, by contrast, American producers expand capacity during a period of increasing demand to position themselves for the upswing, they must dispose of the increased product entirely in their own markets or permit the extra capacity to lie idle. Thus, rapid Japanese expansion in closed domestic markets risks turning foreign markets into residual or secondary markets for excess Japanese capacity; this does not imply dumping or predatory pricing, but it is a logical consequence of a secure home market base. Even a relatively insulated market will therefore give production advantages to Japanese firms at the same time that it tends to insulate them for the consequences of any downturn in demand. Fourth, American firms cannot consolidate a competitive position in the Japanese market if domestic arrangements encourage Japanese firms to buy from local producers regardless of cost-quality advantages.

The immediate United States problem is that Japanese government policies to sponsor the development of a competitive electronics sector and the legacies of that policy slant the terms of worldwide semiconductor competition toward the Japanese relative advantage in production and away from relative advantage of American firms in market development and innovation. The broader policy question is how the United States should respond to foreign efforts to create a comparative advantage in the advanced technology sectors on which our industrial future must rest.

II. Policy for Trade and Development

This essay has assumed that the evolution of the integrated circuit sector will shape industrial development in all advanced countries. Just as the automobile industry altered the organization of our economy and society, the integrated circuit industry makes possible new products, transforms existing goods, and changes the ways that all products will be made. Those countries which most effectively apply the possibilities of microcircuitry in their national economies will grow in strength and wealth relative to the others.

The policy recommended here has two intertwined components: trade policy and domestic development policy. First, American policy must actively pursue open trade in electronic goods. The obstacles to free trade go beyond the direct protection of the domestic market. They are fundamentally entangled with policies of government procurement, industrial promotion, and the regulation of competition. The Tokyo Round trade negotiations in the 1970s anticipated these conflicts, but the substance of the Tokyo Round agreements will be resolved in specific trade disputes. When the high-growth sectors are at issue, it will be increasingly difficult to establish general rules that apply to all sectors or to exchange tariff reductions in different sectors to achieve an overall balance between nations. Trade negotiations will have to focus on the actual workings of trade and competition in specific sectors. In semiconductor trade, the failure to resolve these problems will lead to a mercantile scramble for national advantage. Second, domestic policy should assure that shortages of manpower, finance, and research and development do not constrain the expansion and competitive position of the American segment of this worldwide industry. We propose, in essence, that the U.S. government should play its classic roles: provide the infrastructure to permit industrial expansion, and make the markets work more effectively. American policies to promote the competitive position of the American semiconductor industry should serve as a signal that efforts by foreign governments to spend their way to a comparative advantage in sectors of long-run significance to the United States will be matched by the American government.

Trade Policy and Semiconductor Development

American policy to defend its advantage in advanced electronic products will give substance to the general commitments to remove non-tariff barriers to trade made by all GATT adherents during the most recent round of negotiations. The case of integrated circuits should be seen as paradigmatic of competition in advanced technology industries where government support and private collaboration can serve to create real competitive advantage. The competitive battle for leadership in this industry has become a fight between American and Japanese producers fought out in American and European markets. The most pressing problem in the American semicoductor industry is the Japanese surge, and it is that what we shall address here.

Japan is now a mature, advanced industrial economy. Its electronics sector includes giant and financially powerful firms which are internationally competitive companies. Open access for foreign producers in electronics systems and component markets in Japan must be the counterpart of Japan's entry in force onto international markets for electronics. National treatment for American firms operating in Japan is another way of expressing the goal. We argued in Chapters Two and Three that both government policies and the pattern of inter-company specialization evident in Japan serve to exclude Americans from that market. While we recognize a growing Japanese commitment to open their economy as they become a more powerful force in international markets, the extent and pace of that opening remains important. Closed domestic markets and discriminatory treatment of American firms, this essay has contended, have provided substantial advantages to Japanese firms competing in international markets. They are intended to give a competitive edge to Japanese firms and to reshape international patterns of comparative advantage. The general policy question is where the American government can and ought to respond to political efforts to reshape markets.

A closed market and government promotion aimed at import substitution should produce a very predictable trade pattern in electronics: the most advanced goods will be imported until domestic producers can make them; when they can, domestic production will be abruptly substituted for imports. Our premise is that the local producer, at the beginning of domestic production, would not be expected to be fully competitive in price-quality terms with the foreign producer. (Otherwise, policies of protection would not have been required.) A pattern of aggressive import substitution blurs easily into actual market closure; but we judge implausible and inconsistent with the economics of the industry an argument that Japanese producers upon entering production consistently have an immediate and dominant competitive advantage over American firms that are selling advanced products in Japan.

In open competition within Japan, American producers should retain at least a portion of the market or specific products that a technological monopoly initially won for them. Local producers may initially win sales because of specific market advantages, or they may use captive capacity to achieve the volumes that allow them to match the foreign competitors' costs. In an open market American firms would lose market share slowly when Japanese production began, whereas in a closed market the American market share would drop off abruptly. Figure 3 illustrates this notion. In any given product, the pattern could differ. A Japanese breakthrough might provide an immediate product or production advantage in a specific product. However, the overall pattern of trade in a range of semiconductor products in an open market should see American producers losing market share slowly to Japanese producers but retaining a permanent market position based on their initial advantage. That pattern of open trade is described in Figure 4. Continuous repetition of the pattern in Figure 2, the rapid fall-off in U.S. sales, would be prima facie evidence of market closure. American integrated circuit manufacturers retain the international lead in the broad range of products. It is therefore hard to make a case that their failure to penetrate Japanese markets results simply from competitive weakness. Given the history of discrimination -- as well as the evidence in Chapters Two and Three that closed markets and difficulty of access have been used as critical parts of Japanese development strategies and have deeply influenced corporate tactics -- the burden rests on the Japanese to demonstrate that their markets are in fact open. An end to discrimination could be observed by closely monitoring trade involving American companies selling in the Japanese market, the Americans locate plants, and by monitoring the activities of Japanese buyers in the Japanese market. Such monitoring mechanisms would provide a basis for policy debate and would also serve to test the argument elaborated here.

If Japanese markets are in fact opening, then such a system of monitoring could lay to rest foreign claims of discrimination. If trade patterns that would be predicted by discrimination are observed, then negotiations to identify and remove

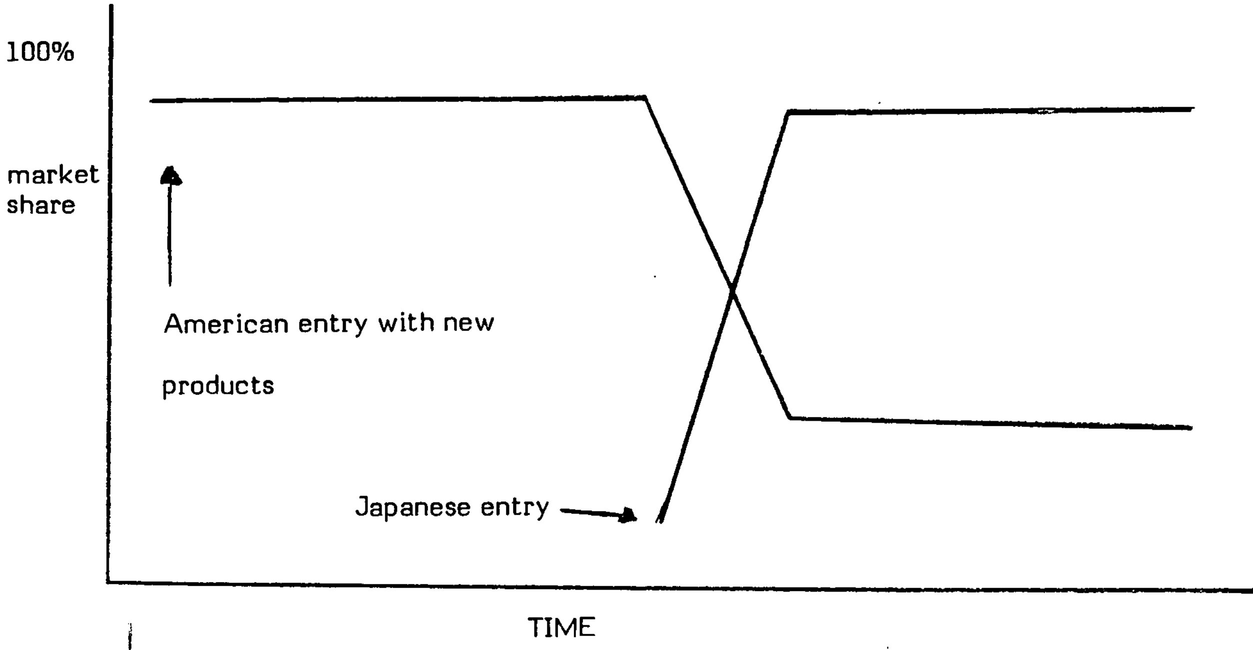

FIGURE 3: Closed Trade.

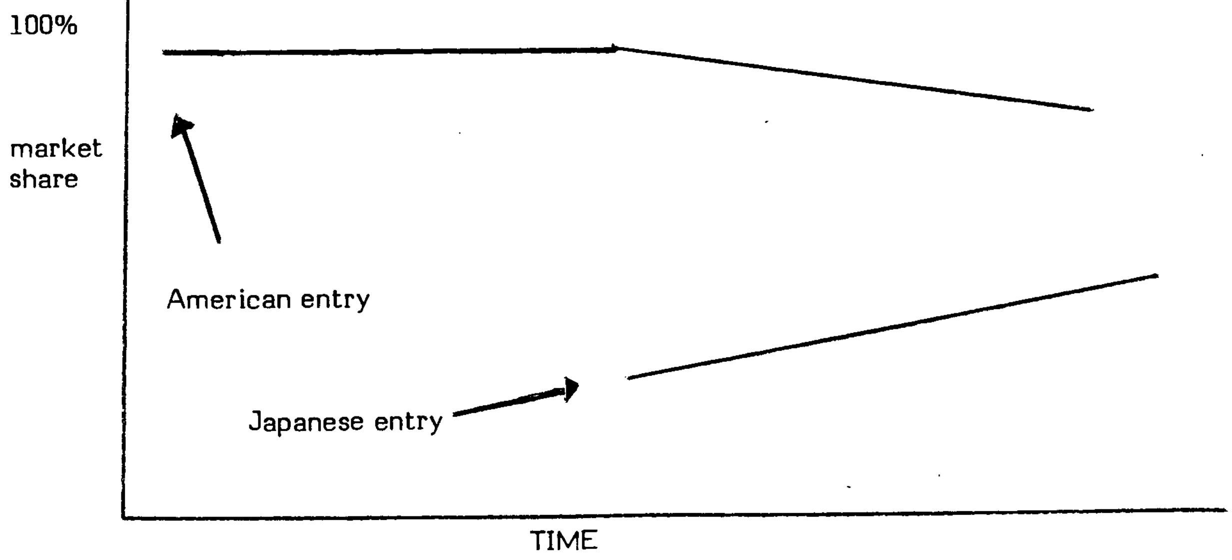

FIGURE 4: Open Trade.

the mechanisms that block free trade should be considered. The quick end to discrimination rather than a slow erosion of barriers to American entry in Japan should be the goal of our policy, and the very fact of monitoring should speed the opening of the market. The details of that system would have to be worked out later, but the logic is clear.

Three types of trade flows should be monitored. First, we must monitor the American position in the Japanese market. As we have argued here, a continuation of traditional company and government policies of rapid import substitution would lead to a rapid drop-off in American sales of advanced products following the first Japanese entry, and to a permanent American loss of those markets. An open market would see a slow drop-off of American market share following Japanese entry into a new product. The Americans would permanently retain an important share of the market. The question is basic: are American producers to be permitted to consolidate an enduring position in the Japanese markets based on their product innovation, or is their initial position to be undermined as a matter of Japanese government policy or industry strategy? Second, we should monitor the availability of Japanese products, production equipment, and know-how to American producers. Rumors abound that Japanese products, equipment, and know-how that are commercially available to Japanese buyers in the Japanese market are not available to American firms. For example, Japanese production equipment crucial to competitive manufacturing is often said not to be easily available to American companies. Third, we must carefully observe product entry strategies used by the Japanese in the American market.

In addition to monitoring competition in semiconductor markets, two other developments need to be closely watched. First, open markets in final electronics systems are another requirement for ending trade discrimination in semiconductor devices. The line between systems and devices is blurring and discrimination in one market is in fact discrimination in the other. Foreign equipment producers are likely to be easier for foreign companies to sell to. Thus discrimination in component and equipment markets reinforce each other. An end to discrimination in electronics systems will require national treatment of American producers in Japanese government procurement, policies and an end to encouragement by that government to private buyers to purchase Japanese equipment. Second, Japanese research and development programs must be open to American companies producing in Japan. Technical results diffused among Japanese producers should be entirely available to American firms. Either research and development programs are aimed at advancing generic technologies and are not direct commercial developments, in which case American participation in such programs should be welcome; or they are competitive applications that are intended to advance Japanese competitive position and encourage the market specialization among Japanese producers that we described in Chapter Two. Failure to make the results available or to permit full participation by American companies should be considered as a government-organized challenge to the American industry.

In sum, the electronics industries in Japan and the United States are organized very differently. These national differences in industry structure and government relations with industry have directly affected patterns of international trade in electronics. Since national differences in domestic structure affect trade in these sectors so profoundly, domestic policies inevitably become the subject of negotiations between nations. In electronics, open trade will require both open borders and national treatment for foreign companies. The alternative is, simply, a fruitless segmentation of world markets and endless international trade conflict.

A Domestic Policy for the Electronic Future

An American policy to lift the constraints on the expansion of American firms and to strengthen their competitive position in international markets should be implemented while open international markets are pursued. The promotional policies and market arrangements abroad intended to accelerate the expansion of the electronics sectors and to create competitive advantage in them is the primary justification for rethinking domestic polices for electronics. In the absence of a challenge from abroad we would have to balance the dislocations of specific parts of the community that are displaced by the introduction of electronics against the gains to the electronics sector and the community of more rapid growth. Were the United States insulated, the appropriate policy might not be clear. But it is evident that international markets do in fact force our hand. In recent years a wide variety of policies have determined the structure of the semiconductor industry. Without intending to shape the industry, antitrust policy placed limitations on the largest producers, while tax incentives for venture capital and stock options facilitated the entry of new enterprises. Similarly, special tariff policies encouraged the internationalization of production. In the industry's early years Defense Department procurement policies actively accelerated the advance and above all the diffusion of technology. More recent defense purchases have represented only a small fraction of the market. Moreover, the military's needs are not in the mainstream of the industry's evolution. In our analysis of Japanese entry into the American market, defense procurement was not a factor at all. It re-entered after 1976, when the Defense Department recognized that it could no longer dominate the semiconductor markets, but rather had to harness market forces to its own purposes. The program it developed, the Very High Speed Integrated Circuit Program, is an imaginative use of procurement techniques to promote innovations. Nevertheless, military procurement can no longer in itself substitute for a civilian industry policy.

The current policy task is to assure conditions for the continued competitive development of the American semiconductor and electronics sectors. The United States electronics firms, which have long dominated the international market for integrated circuits, have demonstrated the capacity to adjust their strategies to meet the challenges of rapid market growth and swift technological development; and indeed the electronics sector's flexibility has been a key to the success with which it has adjusted and is presently responding to the current international market. Yet the very diversity of firm capacities and strategies poses a difficult problem for United States policy. In a growth sector, market outcomes are inherently uncertain. It is not possible to know which firms will succeed, let alone to discover whether they will be predominantly merchant firms or integrated systems houses; and it is certainly impossible to predict which product or production technologies will finally win market acceptance. The technologies that will be dominant, the firms that will be successful, and the resulting structure of the industry cannot be determined. In this regard the semiconductor industry is no different from the automobile industry in its early and volatile years. In a declining industry where markets are more stable, industrial structure more fixed, and product and process technologies more mature, government policy may seek to direct or assist industrial adjustment from a known condition toward a preferred outcome. Indeed, because these technologies and markets are stable, industrially backward countries are often able to direct the expansion of traditional sectors. Thus Japanese and French planners helped manage the expansion of their economies in the postwar years with maps of the future drawn by observing the countries they were pursuing. However, in a growth sector the attempt to tailor policy toward any preferred set of outcomes runs the risk of foreclosing real market opportunities and thereby undermining potential but as yet unrealized or unseen strengths of the domestic sector. In fact, as we have seen in Chapter Two's discussion of early Japanese government attempts to structure the developments of the computer industry, the market may rapidly make the best-laid plans of policy obsolete.

American policy must avoid prescribing outcomes which the market itself has yet to resolve. Instead, policy should be directed toward sustaining and enhancing the competitiveness of the domestic sector. For the individual firm, competitiveness means the capacity to respond to changes in the market in such a way as to leave it well positioned to respond to subsequent market opportunities and challenges. Thus we should direct policies toward removing the constraints on growth. First, policies should assure the technological manpower and financial resources for continued expansion. Second, they should address the particular problems of the merchant sector, a segment of the industry has been crucial to the dynamic advance of the whole industry. Third, policies should help modulate the effect of business cycles on the small- and medium-sized firms. In a growth sector, firms must add capacity as fast or faster than the market expands, or they will risk losing their competitive position as the industry matures. Such rapid expansion, though, makes growing firms very vulnerable to downturns of the business cycle, particularly if they expand with debt financing. When competing with foreign companies which have the financial resources to continue capacity-expansion and research plans during recessions, small and financially constrained firms are at a serious disadvantage. Policies should be devised that permit these firms to weather downturns without cutting back on their plans to prepare themselves for the next business upturn. In an entirely self-contained national market, one factor in domestic competition would be corporate skill at managing during downturns. At this moment in history, the American industry is competing with Japanese rivals that are integrated firms with extensive financing and well situated to use downturns to their advantage in the American market. The policy problem is changed by this. We must recognize, of course, that successful macro-economic policies which assure stable growth provide the best remedy for the difficulties of these firms, as they do for the whole economy. The 1974-1975 recession, as much as the financial structure of American firms, created the opening for Japanese entry. Yet because business cycles will not be eliminated, their consequences for growth sectors in intense international competition may have to be modulated.

Research and Development. The rapid technological advance in integrated circuits is based on a broad and expensive research and development effort, and the competitive advantage of American firms in world markets has been their rapid innovation in production processes and applications. At least in some advanced products -- notably commodity memory chips such as the presently popular 16K RAMs and 64K and 256K RAM circuits, through which the battle for pre-eminence in the next generations of products will be fought -- the Japanese have eliminated that advantage. It is essential to assure that American firms have the internal resources to remain competitive in the successive technology races in which the industry will engage, and that the public investment in the pool of technology on which those advances are made is sustained at a steady level.

The market for new ideas presents one of the classic economic examples of the need for government. The economic paradigm of the perfectly competitive market producing the socially optimal solution to the problems of production and allocation depends crucially on exchanges -- consumers paying a price for the benefit received, and producers just covering the costs of producing the last unit of production. But new ideas are subject to <u>non-rival</u> consumption: it costs nothing to provide the good to the additional user. The "price" should be driven down to its marginal cost to provide the socially optimal consumption of the new idea. But in that case the producer will receive nothing for his idea, and thus have no incentive to produce it. New ideas are an example of what economists call "public goods." The theoretical solution to a public goods problem is to tax consumers for the benefits received and to use the money to cover the costs of producing the goods. This theoretical solution has serious practical difficulties, however, not the least of which is determining how much benefit each consumer is receiving.

The patent system is the compromise which our country generally relies on to overcome the "public good" nature of new ideas. When a new idea is embodied in a product or process, the inventor has the right for a limited period of time to charge users of the product or process in exchange for disclosing his idea in the patent. But even the non-ideal solution of the patent system appears to function poorly in the semiconductor industry. The infinite variability of solutions to technical problems in the industry means that rivals may appropriate much of the value of a new invention disclosed in a patent without legally violating it. Even without patent disclosures, reverse engineering -- working back from rival product to principle -- makes imitation possible. Innovators can only hope to appropriate the benefit conferred by their inventions for a short period of time. Because producers of the new ideas do not receive the full value of the benefits stemming from their invention, many socially optimal avenues of research -- those whose benefits outweigh their costs -- go unexplored.

The problem is least serious when the producer can capture much of the value generated by his idea. Research very closely related to a commercially feasible product may be hampered only slightly. By contrast, new knowledge gained from basic research in physics and chemistry may generate tremendous long-term benefits to society even though the knowledge cannot be immediately used in a new product. By the time the idea is applied to commercial products, other firms who did not bear the cost of developing the idea may be prepared to supply the market as well. There are at least two ways to overcome the problems presented by the public goods aspect of innovation. First, government can expand the research infrastructure on which all firms draw; and second, government may subsidize the research conducted by private firms to bring private gain and public benefit into line.

Fundamental technology from which particular product strategies are drawn should be treated as part of the industrial infrastructure. The infrastructure of fundamental technology consists of more than a pool of patents; it is a set of connections between firms, research institutions, and universities. Indeed, through the mechanism of industry association research groups -- which if properly structured do not violate antitrust laws -- firms may collaborate directly. The flow of people and "know-how" along the connections between these institutions is equally important. This technology infrastructure should facilitate high-risk research strategies that might be too expensive or uncertain for any single firm; it should finance basic research in general; and it should widely diffuse those advances throughout the industry. In sum, the research infrastructure provides a public good -- the basic knowledge which is useful to all and which cannot be withheld from those who refuse to pay a share of the cost. Policies to support the research infrastructure must be sufficient to allow the American companies that are part of the network to compete successfully with firms who are involved in other national research networks. The quality and volume of the research, as well as the linkages that assure its diffusion, are the best measure of the adequacy of the infrastructure. The sources of funding should be arranged to assure a stable and long-term effort not vulnerable to the whims of short-term budgeting. Consequently, wherever possible some form of a tax on production or sales imposed by government, or a pseudo-tax imposed by the participating firms themselves, should be employed.

There can be no single solution to expanding the research infrastructure; rather, a variety of private and public solutions will be necessary. The Semiconductor Industry Association has itself organized within its membership a joint research program intended to supplement the efforts of individual companies. It will be directed at long-term, science-related projects which are not currently being pursued by private industry or the universities. The joint research project will be a non-profit endeavor financed primarily by contributions from participating private firms. Access to the research in progress will be limited to contributing firms, but access to final research results will be made available by license on common terms to all applicants. Membership in the effort will be limited to those firms having substantial integrated circuit manufacturing capacities in the United States. This program will use existing facilities, and will provide finance for specific projects rather than establishing its own operation. The program does not depend on government support directly, but its success will in all likelihood depend upon the terms of tax arrangements for contributions to university research and the interpretation of antitrust regulation. The initial commitment in 1982 will be seven to eight million dollars a year, with a yearly budget of some forty million dollars a year envisaged.

State programs intended to support "local" firms are now emerging in several parts of the country. These public programs are second avenue to assure adequate R&D. For example, the California Micro-Project call for programs to be proposed jointly by industry and university researchers to an oversight board representing both communities. State funds would be provided to match industry commitments up to a total of one million dollars. Such a program should help establish long-term links between industry and researchers.

Perhaps the most interesting current government program is the Department of Defense effort called VHSIC (very high speed integrated circuit). The purposes of this program are three: (1) to advance the date of common commercial use of VLSI (very large scale integrated circuits); (2) to increase the speed at which advanced circuit technologies are applied to military systems; and (3) to assure the development of advanced circuits to meet corporate and military requirements of circuit speed and built-in verification. The military is more interested in the speed of electronic operations than with the cost per function that primarily concerns civilian users. Very large scale integration increases the density of the bits that compose a circuit, reducing cost, but the further reduction in circuit size does not directly address the speed problem. Nonetheless, alternate technological routes for achieving greater density have different implications for circuit speed, and the military problem is to push research in directions that yield technical solutions that are commercially feasible in civilian markets. The VHSIC program created a series of research teams -- involving systems producers, semiconductor producers, and research centers -- that would compete for follow-on contracts. Each system producer had to promise that circuits of specific characteristics, if developed, would be incorporated into their existing systems. In essence the Defense Department was trying to buy applications of advanced semiconductor technology to military systems, but the choice of technological direction was primarily left to the systems user and the would-be circuit supplier. Moreover, since the program as a whole advances the date of commercial uses of

VLSI circuits, it forces all producers to make a substantial research commitment to keep pace. This speeds diffusion of new technologies.

The VHSIC approach could also be used for the development of civilian products. There is no need to limit such efforts to military procurements. The difficulty, of course, is agreeing on which civilian goods deserve a boost through government funding and which companies deserve the advantage of participation in the program. The development of automated production equipment that might permit an accelerated growth in productivity would seem an obvious choice, but labor might well contend that government should not accelerate the pace of labor displacement inherent in automated production. Nonetheless, a Civilian Applications Program might be established in which the choice of application was part of the competition for funds. A Center for Productivity in Manufacturing must be a component of such a program.

All foreign companies producing in the United States should be allowed in principle to participate in all procurement and development programs, except where the final electronics systems involved impose security constraints. Foreign company participation should, in practice, be formally contingent on American participation in the joint research and development programs of government and industry in the home country of those firms. Thus, Japanese participation in any joint industry program or Department of Defense effort would be contingent on American company access to such Japanese programs as the VLSI development program, the Fifth Generation Computer Program, and other government or public company research projects intended to support research that will be useful to the entire industry. In anticipation of controversy over the extent of participation and the degree of access of American companies to foreign programs, a system for rapid and binding arbitration of such controversies should be established as a matter of law. American research and development should explicitly be used as a bargaining chit to gain access to foreign markets. American government efforts in supported research should establish that in high-technology industries open trade means reciprocal exchange of the results of fundamental research even if there are foreseeable commercial applications.

The alternative to government-sponsored research or joint industry efforts is subsidy. The recent federal Research and Development Tax credit represents a subsidy to private research. It provides an incentive for companies to expand the levels of R&D funding. The tax credit is based on incremental spending -- that is, the difference between this year's effort and the average of the previous years of spending. The advantage of this formula is that the biggest tax savings should go to successful and growing firms. (The application of an across-the-board tax credit for a firm with stable markets might result in a diversion of the tax savings to some other use.) While this tax arrangement is helpful, other problems remain. One task is to help companies sustain research and development through cyclical downturns. It is in the public interest to help companies, limit during downturns to limit cuts in R&D investments, which are at the core of a long-term strategy. Therefore, one might imagine an across-the-board R&D tax credit during periods of business downturns, if the rate of increase in such R&D spendings were not reduced. Alternatively, a pool of funds from which a company might draw during downturns for R&D, however defined, could be created by a special tax credit placed into an "escrow" account. Sweden has operated a program like this to support business investment.

Finance as a Constraint on the Growth of American Firms. The central financial problem in the integrated circuit industry is the availability of capital for small- and medium-sized companies to expand production and sustain their research efforts. In our view, the availability of funds is unquestionably as important as their cost. The question is not simply the direct effect of the cost or availability of funds on corporate profits, but rather the influence of these factors on the strategies a firm can adopt. Current financial constraints encourage short-term perspectives in American firms, which must compete with foreign firms that have financial structures which permit them to adopt a long-term horizon. If American firms in a recession do not have the funds to build the capacity they need to hold market share in the next upturn, then the availability of finance is a constraint on their strategies. As noted in Chapter Two, capacity expansion was cut back by American firms during the recession of 1974-1975, while their Japanese counterparts continued to invest. The result was a competitive opening for the Japanese.

The integrated circuit industry is becoming more capital-intensive. Estimates suggest that in the last three or four years production costs have increased tenfold. The consequence is that finance will increasingly become a constraint on the expansion of American IC companies. The problems are probably most serious for medium-sized firms. Small firms just starting can reportedly find venture capital easily, but the medium-sized firms are unable either to borrow heavily in a cyclical industry (debt represents a fixed costs), or to use profits from unrelated businesses, which larger integrated firms can do. Thus even a firm with sales nearing a billion dollars annually will appear to be a risky operation. As argued in Chapter Two, a number of informal arrangements, in addition to formal mergers, have overcome some of the problems facing medium-sized firms competing in an expanding sector. Those arrangements include cross-licensing and development contracts that transfer part of the risk of R&D to a subcontractor or partner.

The Japanese financial system is organized around bank loans, with prices in most markets dictated by the government. Government has sought to assure high levels of savings and low-cost credit to growth sectors. Finance, in the view of many Japanese commentators, is the crucial instrument of industrial policy. Indeed, loans to targeted sectors are implicitly guaranteed by the Japanese government, which assures the availability of credit and lowers its cost. There is every evidence that differences in corporate financial arrangements affect corporate strategies, with government-guaranteed credit encouraging pursuit of market share rather than immediate profit. The Japanese, as a matter of policy, bias the financial system toward priority sectors. In a sense, the American government also gives priority to some uses of capital, particularly housing. The multitude of loan guarantee programs which cumulatively represent government biasing of our capital-market-based financial system are not, however, formulated to promote the expansion of the growth sectors on which the health of the economy rests. We should be be allowing the different emphasis and structure of the American financial system to place our firms at a competitive disadvantage.

Policy must seek to place our growth sectors on a financial footing equal to that of our foreign competitors. Recent tax legislation that provides for more accelerated depreciation and R&D tax credits will undoubtedly make more funds available to firms, but it does not in itself resolve the central financial problems these firms face. For government the tasks are to assure that expanding firms in growth sectors have the funds they need for expansion, and to insulate the growth firms against purely cyclical business downturns so that the real battle in the marketplace is a technological and marketing struggle.

Two policy approaches seem possible. First, financial markets will have to be encouraged to funnel venture capital into expanding firms. The specifics of tax policy are less important than an agreement that we need tax arrangements to facilitate expansion of capacity and R&D in growth sectors. The device of the R&D partnership is one example of a tax innovation which begins, if awkwardly, to address this problem. The creative use of public pension funds may also give an impetus to financial market innovations that would help companies gain quicker market acceptance. Second, some form of targeted tax legislation, aimed not at a paticular sector but rather at growth sectors in general, may be required to modulate the effect of business downturns on the industries that will fuel growth. Certainly, a smoother path of growth would reduce the need for sector specific protections against downturns, but business cycles do occur. Many of our foreign competitors insulate critical sectors against the consequences of recessions which places our firms at a disadvantage. To formulate American policy, growth sectors could be defined by two characteristics: they must be of a certain minimum size (the precise level is not important here); and (2) they must be growing at a specified pace (such as 15 percent) a year in sales). Depreciation schedules for the growth sector might be accelerated in general. However, the most important goal of tax arrangements would be to reduce the risk of debt. Double counting of interest against taxes during a downturn in industry-wide sales, for example, might make the risks of expansion easier to manage. The policy objective is clear: assure that financial constraints do not limit the expansion of growth sectors or handicap them in international competition.

The problem of attracting capital for the semiconductor industry cannot be understood in isolation. General economic conditions and overall savings rates will affect the possibilities of this sector as they do all others. Yet we must also recognize that the problem of attracting capital to growth sectors involves freeing capital from competing investments. For example, a long list of policies pursued by the Federal government has directed resources toward the housing sector. Americans spend one out of five dollars for investment on residential construction. The deregulation of the savings and loan industry indicates some reduction in the priority to be given to housing in future years. In contrast, the recent changes in depreciation schedules have drastically reduced the write-off times for new buildings, with only minor reductions for new equipment. The attractiveness of investing in commercial construction has come at the expense of manufacturing. In a rapidly changing industry like electronics, even the current write-offs do not appear to capture the full economic depreciation of equipment that must be replaced every year or two to keep pace with technological developments. In its starkest terms, the struggle for capital may emerge as a battle between the existing industrial structure and the need to prepare for America's industrial future.

Manpower Constraints. While financial and research infrastructure are probably of the most immediate importance, assuring adequate manpower will prove of equally great importance in the next years. The expansion of the electronics industry requires ever greater numbers of engineers. If the ratio of engineers to production personnel were to remain constant over the next ten years, we would expect a steady increase in demand for the engineers needed to design and apply these products. Nonetheless, the number of engineers graduated has not risen over the last several years; in fact, it has fallen. We can speculate that in the past, manpower was not a constraint because the post-Sputnik expansion of science and engineering education was followed by a cutback in aerospace programs. This left many engineers unemployed. Unlike the earlier space build-up, the current electronics expansion has its roots in the civilian sector, and it will not be reversed by any particular government procurement decision. Indeed, the present military equipment build-up will strain the existing supplies of engineers even further. Whether this latest build-up is reversed, the expansion of civilian electronics is permanent. Table 17 indicates the problem: America has produced a constant number of engineers in a period in which expanding numbers will be needed, whereas Japan has quite consciously expanded the pool of engineers.

Table 17

NATIONAL SUPPLIES OF ENGINEERING GRADUATES

	Electrical Engineering Graduates Per Capita (per million)				Annual Electrical Engineering Graduates (Total) U.S. and Japan		
Country	1965	1970	1975	1977	Year	U.S.	Japan
France	20	34	28	33	1969	16,282	11,848
					1970	16,844	13,889
Japan	82	133	162	185	1971	17,403	15,15
					1972	17,632	16,052
U.K.	32	46	45	46	1973	16,815	17,345
					1974	15,749	17,419
U.S.	..	85	67	66	1975	14,537	18,040
					1976	14,380	18,258
W. Germany	16	11	48	109	1977	14,085	19,257
					1978	14,701	20,126
					1979	16,093	21,435

SOURCE: S.I.A, The International Microelectronic Challenge, May 1981.

The manpower shortage will not be limited to engineers. Unless high-level computer languages are developed that dramatically reduce the man-hours involved in the development of software, programming will require ever increasing numbers of programmers and software developers. A detailed evaluation of the changing educational requirements is outside this study's focus on trade and competition, but the issue must be confronted. Failure to assure adequate personnel for the industry is having two consequences: high salaries for current engineers and programmers and a slowed expansion of the American segment of the industry because American companies are moving design activities abroad in order to escape this manpower constraint.

Our government's task should be seen broadly. It is nothing less than educating a society for the electronics era we are entering. This means that literacy in the most basic sense may have to be redefined, and the curricula from grade school through high school significantly changed. We must go beyond expanding the supply of engineers and physicists; we must give all citizens more of the technical skills they will need to live in a new age. We must help the national community understand the changes in the social world and in work organization that will accompany the arrival of the electronics era. Since educational planning has been returned to the state governments, it is essential that a careful examination of the curricula, equipment, and teacher requirements be begun at once in state and local educational communities.

III. Preparing for the Electronics Era

The diffusion and advance of microcircuits portend a basic shift in the organization of the economy and society. The benefits may be widely spread, but the short-term dislocations will be borne by specific groups. Historically, the social dislocations that accompany industrial change have brought conflict and resistance, and individual efforts to avert the costs of change have slowed the advance of innovation and productivity. Yet we must recognize that for the individuals displaced, the losses will seem severe and well worth resisting. Government policy should consciously attempt to assure that the costs of the electronics transformation are not inequitably borne by particular segments of the community. The programs for industry assistance proposed here will find broad support only if the collective gains are clearly understood and the losses to particular groups diffused and borne by the community as a whole. For labor, outright resistance to production changes that would mean higher productivity can only lead to a general decline in the competitiveness of American industry. The problems that accompany an electronics future cannot be escaped, but they can be addressed and solved jointly. We must begin to explore consciously what will be required of industry, government, labor, and communities to adjust to the world of electronics.

NOTES

INTRODUCTION

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2. *Vision of MITI Policies in the 1980s.*

CHAPTER ONE

1. Semiconductor Industry Association, *The International Micro-Electronic Challenge* (Cupertino, 1981), p. 35.

2. For a more detailed discussion of the impact of the Department of Defense on the development of the civilian electronics industry in the United States, two recent studies are of particular interest: Norman Asher and Leland Strom, *The Role of the Department of Defense in the Development of Integrated Circuits* (Institute for Defense Analyses, Arlington, Virginia, 1977); James Utterback and Albert Murray, *The Influence of Defense Procurement. and Sponsorship of Research and Development on the Development of Civilian Electronics Industry* (Center for Policy Alternatives), (M.I.T., 1977).

3. U.S. Department of Commerce, *A Report on the U.S. Semiconductor Industry* (Washington, D.C., Government Printing Office, 1979), p. 1.

4. Ian Mackintosh, *Microelectronics in the 1980's* (London, Mackintosh Publications Ltd., 1979), p. 66, Table II.

5. Utterback and Murray, *The Influence of Defense Procurement*, p. 3.

6. Asher and Strom, *The Role of the Department of Defense in the Development of Integrated Circuits*, pp. 4, 17.

7. *Ibid.*, p. 17.

8. *Ibid.*, p. 45.

9. U.S. Federal Trade Commission, *Staff Report on the Semiconductor Industry*, (Washington D.C., Government Printing Office, 1977), p. 11, Table II-3.

10. U.S. Department of Commerce, A Report on the U.S. Semiconductor Industry, p. 46, Table 3.5.

11. Mackintosh, Microelectronics in the 1980's, p. 65.

12. For an excellent study of the evolution of the computer industry, see John T. Sima, The Computer Industry (Lexington, Lexington Books, 1975).

13. Mackintosh, Microelectronics in the 1980's, p. 65.

14. Charles River Associates, Innovation, Competition, and Government Policy in the Semiconductor Industry (Boston, 1980) p. 2-3. A more detailed analysis of the product "races" discussed below can be found in Chapter 4 of the Charles River study.

15. Federal Trade Commission, Staff Report on the Semiconductor Industry, p. 26, Table 11-9.

16. Ibid., p. 11, Table II-3.

17. Charles River Associates, Innovation, Competition and Government Policy, pp. 4-16, 4-17.

18. Ibid., p. 4-18.

19. Semiconductor Industry Association, The International Microelectronic Challenge (Cupertino, 1981), p. 35.

20. Department of Commerce, A Report on the U.S. Semiconductor Industry, p. 56.

21. Federal Trade Commission, Staff Report on the Semiconductor Industry, p. 26, Table II-9.

22. Charles River Associates, Innovation, Competition and Government Policy, p. 2-9.

23. U.S. House of Representatives, Ways and Means Committee, Subcommittee on Trade, Competitive Factors Influencing World Trade in Semiconductors (Washington D.C., Government Printing Office, 1980), p. 64, Table 1.

24. Department of Commerce, A Report on the U.S. Semiconductor Industry, pp. 46, 50.

25. "The Mess in Consumer Electronics," Dun's Review (June 1977), p. 72; and "The Great Digital Watch Shakeout," Business Week, May 2, 1977, p. 78.

26. Charles River Associates, Innovation, Competition, and Government Policy, p. 4-23.

27. Ibid., pp. 4-22 to 4-28.

28. Mackintosh, *Microelectronics in the 1980's*, p. 65.

29. Lund, Sirba and James Utterback, *Microprocessor Applications: Cases and Observations* (Center for Policy Alternatives, M.I.T., 1979), p. 1.

30. Two excellent studies should be consulted for greater detail on the development of microprocessor applications: Lund, Sirba, and Utterback, *Microprocessor Applications*; Economic Intelligence Unit, Ltd., *Chips in the 1980's: The Application of Microelectronic Technology in Products for Consumer and Business Markets* (June 1979).

31. Charles River Associates' account of the technology race in the microprocessors market provides an overview to the price wars and product development competition during the period 1971-1979. See *Innovation, Competition, and Government Policy in the Semiconductor Industry*, p. 4-30 ff.

32. Based on statistics from industry sources.

33. Based on statistics from industry sources.

34. William Finan, *The International Transfer of Semiconductor Technology Through U.S.-Based Firms* (National Science Foundation, 1975), p. 23.

35. "1980 Semiconductors Forum," *The Rosen Electronics Letter* (Rosen Research Inc, New York, July 14, 1980) p. 80-10 ff.

36. This terminology is borrowed from Finan's study, *The International Transfer of Semiconductor Technology Through U.S.-Based Firms*. Finan adds a third category, "complete manufacturing facilities," which we shall treat under the discussion of "point-of-sale affiliates."

37. Finan, *The International Transfer of Semiconductor Technology*, p. 60.

38. *Ibid.*, p. 69.

39. For a more detailed discussion of the factors influencing "offshore assembly" activity, see Richard W. Moxan, "Offshore Production in Less-Developed Countries: A Case Study of Multinationality in the Electronics Industry," *The Bulletin*, Nos. 98-99, July 1974; and "Effects of Offshore and Onshore Foreign Direct Investment in Electronics: A Survey" (Report for the Office of Technology Assessment, Washington, D.C., 1980).

40. Finan, *The International Transfer of Semiconductor Technology*, p. 56.

41. Department of Commerce, *A Report on the U.S. Semiconductor Industry*, p. 86.

42. Moxan, "Effects of Offshore and Onshore Foreign Direct Investment on Electronics," p. 24.

43. Finan, The International Transfer of Semiconductor Technology, p.74.

44. Department of Commerce, A Report on the U.S. Semiconductor Industry, pp. 84, 85.

45. This story is dealt with in greater detail in the following chapter on the development of the Japanese industry to which the reader is referred.

46. Finan, The International Transfer of Semiconductor Technology, p.75.

47. Ibid., p. 95.

48. Department of Commerce, A Report on the U.S. Semiconductor Industry, p. 96, n.2.

49. Finan, The International Transfer of Semiconductor Technology, p. 41.

50. Estimated on the basis of statistics in various issues of Electronics News and industry sources.

51. Department of Commerce, A Report on the U.S. Semiconductor Industry, p. 60.

52. The Tarriff Schedules of the United States have been changed since the early 1970s and these integrated circuit parts now can be found in TSUS 7768960.

53. Department of Commerce, A Report on the U.S. Semiconductors Industry, p. 70, Table 4.10.

54. U.S. Department of Commerce, 1980 U.S. Industrial Outlook (Washington, D.C., Government Printing Office, 1980), p. 268.

55. U.S. International Trade Commission, Competitive Factors Influencing World Trade in Integrated Circuits U.S.I.T.C. Publication No. 1013, Washington, D.C., 1979) p. 105.

56. Ibid., p. 104.

57. Ibid., p. 102.

CHAPTER TWO

1. The five are Nippon Electric Co. (NEC), Hitachi, Tokyo Shibaura (Toshiba), Fujitsu, and Mitsubishi. The non-direct participant was Matsushita, Japan's largest consumer electronics company, whose autonomous research capacities and relative independence from the government's "administrative guidance" have been much heralded. The VLSI participants were roughly aligned during the project in two groups which mirrored formal working

arrangements developed during the early 1970s. These were NEC and Toshiba, with their joint NEC-Toshiba Information Systems, CO. (NTIS), and Fujitsu-Hitachi-Mitsubishi, with their Computer Development Lab, Ltd. (CDL).

The subsidies for the VLSI program have been characterized by different sources as either direct subsidies or loan guarantees. As with trade statistics, present publicly available sources of information are simply inadequate to determine the true situation. Implications remain roughly unchanged, however. The public subsidy represents perhaps 10 percent of the value of these companies' combined production of digital MOS IC's during the years of the VLSI project. This is a very rough estimate based on MITI's figures for digital MOS IC production in Japan and our estimate of the percentage of that production which is acccounted for by these five firms. Since most of the VLSI program's thrust involved development of digital MOS IC's, the percentage figure fiven here should be a reasonable representation of the impact of public spending in the VLSI program.

2. Figures vary, but purchases in the first two years were at least some $42 million worth. Purchases in the last two years were expected to be larger. See, for example, Electronic News, 7/19/76, 9/27/76, and 1/31/77.

3. The linked characterization of the industry is suggested by Julian Gresser, High Technology and Japanese Industrial Policy: A Strategy for U.S. Policy Makers (June 26, 1980). The industry's structure will be explained below.

4. Industrial Structure Council, The Vision of MITI Policies in 1980s (translation by the Industrial Bank of Japan, Limited), March 1980, pp. 136, 199, 200.

5. T. J. Pempel, "Japanese Foreign Economic Policy: The Domestic Bases for International Behavior," in Peter J. Katzenstein, ed., Between Power and Plenty (Madison, University of Wisconsin Press, 1978), p. 157.

6. Import percentages are from Vision of MITI Policies, p. 30.

7. Edward F. Denison and William K Chung, "Economic Growth and its Sources," in Hugh Patrick and Henry Rosovsky, eds., Asia's New Giant (Brookings Institution 1976), p. 67.

8. Pempel, "Japanese Foreign Economic Policy," p. 139.

9. John Zysman, Finance and the Politics of Industry (forthcoming, 1981), p. 359.

10. Vision of MITI Policies, p. 31.

11. The quoted term is from Ibid., p. 196.

12. Pempel, "Japanese Foreign Economic Policy," p. 159.

13. The Consulting Group, BA Asia Ltd., The Japanese Semiconductor Industry 1980, p. 145, for greater detail. Hereafter cited as BA 1980.

14. Chase Financial Policy, U.S. and Japanese Semiconductor Industries: A Financial Comparision (1980), pp. 1.5, 1.6. Hereafter cited as Chase.

15. BA 1980, p. 113.

16. Descriptions are culled from The Consulting Group, BA Asia Ltd., The Japanese Semiconductor Industry: An Overview (April 1979), hereafter cited as BA 1979), pp. 160-178; BA 1980, pp. 134-135, 184-204; and Gresser, High Technology and Japanese Industrial Policy, pp. 1-3.

17. Figures that follow are from BA 1979, pp. 80 and 115.

18. BA 1980, p. 148.

19. BA 1980, p. 129.

20. Quoted in Leslie Donald Helm, The Japanese Computer Industry: A Case Study in Industrial Policy (University of California, MA Thesis in Asian Studies, June 11, 1981, unpublished), p. 34.

21. Based on conversations with industry sources.

22. For an elaboration of the remainder of this paragraph, see Gresser, High Technology, pp. 4-7; and BA 1979, pp. 15-19.

23. The firm Keiretsu are as follows (from Chase, p. 8.2):

    Fujitsu Ltd. -- Dai-Ichi Kangyo Bank (DKB) Group
    Hitachi Ltd. (a) -- Hitachi Group
    Matsushita Elec. Industrial (a) -- Matsushita Group
    Mitsubishi Electric Corp. (b) -- Mitsubishi Group
    Nippon Electric Co., Ltd. (b) -- Sumitomo Group
    Toshiba Corporation (a) -- Toshiba-IHI Group

    (a) dominant number of own independent industrial grouping

    (b) former Zaitbatsu (family-dominated industrial and banking combinations formally broken up after World War II, and restructured)

    See Appendix in Chase for the structure and membership of each Keiretsu.

24. S. Miyaski, "Japanese-Type Structure of Big Business," and Yusaku Futatsugi, "The Measurement of Interfirm Relationships" in Kazus Sato, Industry and Business in Japan (M.E. Sharp, White Plains, 1980).

25. H. Ueno, "The Conception and Evolution of Industrial Policy," in Sato, Industry and Business in Japan, pp. 400-407.

26. Richard Caves, "Industrial Organization," in Patrick and Rosowsky, eds., Asia's New Giant, p. 488.

27. Chase, p. 23.

28. For elaboration of what follows, see Chase, Chapter 6.

29. Several of the assumptions of the Chase study, which are crucial to the size of the capital cost differential it asserts are questionable. Most significantly, Chase uses the historical growth rate of stock prices as the measure of the firm's cost of equity. This ignores the relatively light demand on current cash flow made by equity holders who expect returns on uncertain, future earnings (hence a limited drain on current funds). Other questionable assumptions include (1) the very low differential used to compensate for exchange rate changes between dollar and yen, and (2) the use of current (extremely high) costs of debt in the U.S. instead of the historical rates actually paid by U.S. semiconductor firms. There are, finally, other technical problems in the study -- for example, use of the entire integrated Japanese firm instead of the semiconductor division. While, as we suggest, the Chase study's conclusion is plausible, a more careful study would be required to prove that capital is actually cheaper for Japanese firms.

30. These ratios are based on information supplied by industry sources.

31. Figures are from Japan Electronics Industry Development Association (the predecessor to the present Japan EIA).

32. BA 1979, pp. 83 and 48; yen conversion at 212/1 for 1978.

33. Source is John E. Tilton, reprinted in U.S. Federal Trade Commission, Staff Report on the Semiconductor Industry, p. 33. Kobe Kogyo and Fujitsu merged in 1968.

34. On NEC and Fujitsu's orientation, see John E. Tilton, International Diffusion of Technology (Washington D.C., Brookings Institution, 1971) pp. 143, 145.

35. Estimate from industry sources.

36. See generally, Helm, The Japanese Computer Industry.

37. On the above points, see Tilton, in FTC Staff Report, p. 146; Gresser, High Technology, pp. 15, 45, 93 (footnote 42, 95 (footnote 46); and William Finan, The International Transfer of Semiconductor Technology (National Science Foundation 1975), p. 95.

38. Helm, The Japanese Computer Industry, p. 76.

39. On this and prior points see Tilton, in FTC *Staff Report*, p. 148.

40. The following is from Tilton, pp. 146-147.

41. For an elaboration of these policies, see Gresser, *High Technology*, pp. 22-23 and 88-91 and footnotes 27-41.

42. Gresser, *High Technology*, p. 16.

43. Thomas Hout and Ira Magaziner, *Japanese Industrial Policy* (Institute for International Studies, Berkeley 1981), p. 83.

44. On the following, see Gresser, *High Technology*, pp. 16-17 and Mackintosh, Microelectronics in the *1980's*, p. 18.

45. Sources on the foregoing points are Gresser, *High Technology*, p. 19; Hout and Magaziner, *Japanese Industrial Policy*, p. 84; and Helm, *The Japanese Computer Industry*, p. 34.

46. BA 1979, pp. 96, 110, 128.

47. The following is largely from CRT, p. 4-36 to 4-39.

48. Percentages are estimated from figures in DOC, p. 82.

49. The following is from Gresser, pp. 7, 17-18, 20. Gresser does not, of course, situate either the regrouping of the industry or his description of liberalization within the domestic and international market context which we have elaborated above.

50. The preceding is based on correspondence with T. J. Pempel.

51. Gresser, *High Technology*, p. 20.

52. Hout and Magaziner, *Japanese Industrial Policy*, p. 104.

53. The following is from BA 1979, p. 122.

54. This and the following import percentage estimates are from BA 1980, p. 137.

55. *The Economist*, April 5, 1980, p. 75.

56. This and the following figures are from BA 1979, p. 133 and BA 1980, pp. 136-138, 153. Yen/dollar conversions are 274/1 for 1977; 212/1 for 1978; and 250/1 for 1979.

57. On the following, see in particular *Electronic News*, 12/6/76, p. II-33; 4/18/77 p. 1, 4; 10/17/77, p. 56; 1/30/78, p. 58.

58. W. E. Steinmueller, "Studies of U.S. and Japanese Semiconductor Producers -- An Overview" (Stanford University, April 1980), pp. 12-13.

59. Hout and Magaziner, Japanese Industrial Policy, p. 108.

60. BA 1979, p. 57, and for the following figures, p. 35.

61. This paragraph and the quotation are from Hout and Magaziner, Japanese Industrial Policy, p. 108.

CHAPTER THREE

1. Estimated from figures in Fortune, March 23, 1981, p. 116.

2. Business Week, March 30, 1981, pp. 86-87.

3. Based on conversations with industry sources.

4. Author's estimates based on data in BA 1980, pp. 117, 123. Estimated percentages for 1975 and 1976 assume that the U.S.-controlled percentage of total Japanese imports remained roughly the same as in 1978 and 1979. The 1980 figure is an estimate based on industry sources. Actual numbers would have to be radically different to alter the general pattern described in Figure 2.

5. BA 1980, pp. xix-xx.

6. The nature of the Japanese competitive challenge depends, as we have emphasized, on a judgment about the existence of a system of conscious, organized, import substitution. The available evidence is consistent with our position, but the generation of data to test the proposition formally should be an objective of policy. On this point, see Chapter Four.

7. On pricing, see BA 1980, pp. xix-xx.

8. The Economist, 4/26/80, pp. 54-55; see also, Rosen Electronics Letter, July 7, 1980, p. 59.

9. Based on conversations with industry sources.

10. The political response will be touched in the next chapter. It is not described here because it is widely known and has generated both the recent policy studies on the industry and the policy debate which this paper joins.

11. See, for example, stories in Electronic News, 5/29/78, p. 110; 8/28/78, p. 1; 4/25/77, p. 33; 23/27/78, p. 1; 6/4/77, p. 1; 9/14/78, p. 58; 6/27/77, p. 1; 8/27/78, p. 12; 4/17/78, p. 34. See also The Economist, 8/2/80, p. 63-64. See Electronics, 7/5/79, p. 39 for the AMD-Zilog story.

12. On the above, see Electronics News, 6/27/77, p. 1; 8/8/77, p. 46; and 5/1/78, p. 12.

13. For foreign firms, the timing of the acquisition wave seems to be related to a cheap U.S. dollar relative to the acquiring firm's home currency.

14. On the following and for the quote, see remarks by GM-Delco's Frank E. Jaumot, in Rosen Electronics Letter, July 15, 1980, pp. 133-143. See also Business Week, October 8, 1979, pp. 440-443; Electronics News, 4/4/77, p. 40.

15. The following figures are from ICE, Status 1980, "A Report on the Integrated Circuit Industry," pp. 57-66.

16. As advances in semiconductor hardware technology speed the "computerization" of society, yet another new industry is being fostered, the independent software business. Lack of software capability at both the systems level, ("teaching" the machine to function as a computer) and the applications level (enabling the computer to perform specific tasks) is the major structural block to the spread of computer technology. For a good introduction to the emerging software industry and the problems of software development, see "Missing Computer Software," Business Week, September 1, 1980, pp. 46-56.

17. Business Week, August 24, 1981, p. 112.

18. See ibid. for details on the following new entries.

19. On the following, see BA 1980, p.29; and Datamation, 2/28/80/ p. 52-58.

20. See testimony of AMD Vice President George Scalise in Hearings of the U.S. Congress, Joint Economic Committee, Subcommittee, on International Trade, Finance, and Security Economics, July 9, 1981. (Advance copy, p. 48.)

21. Based on conversation with industry sources.

GLOSSARY

A/D Converter	Analog-to-digital converter. A device to convert variable or **analog** signals to digital representation. Also called ADC.
Acess Time	The time interval between the instant that data is called from or delivered to a storage device (memory) and the instant the requested retrieval or storage is complete.
Algorithm	A prescribed set of well-defined rules for the solution of a problem. Algorithms are implemented on a computer by a stored sequence of instructions.
Alignment	The arranging of the **mask** and **wafer** in correct positions, one with respect to the other. Special alignment patterns are normally part of the mask.
Analog	Indicates continuous, non-digital representation of phenomena. An analog voltage, for example, may take any value.
Binary	A system of numbers using 2 as a base in contrast to the decimal system which uses 10 as a base. The binary system requires only two symbols...0 and 1.
Bipolar	Refers to transistors formed with two (N- and P- type) semiconductor types.
Bit	A **binary digit.** A bit is the smallest unit of storage in a digital computer and is used to represent one of the two digits in the **binary** number system.
Bus	A circuit or group of circuits which provide a communication path between two or more devices.
Byte	A set of contiguous **binary bits,** usually eight, which are operated on as a unit. A Byte can also be a sub-set of a computer **word.**
CMOS	Complementary Metal Oxide Semiconductor. A logic family made by combining N-channel and P-channel **MOS** transistors.
CPU	Central Processor Unit. That part of a computer that fetches, decodes, and executes program instructions and maintains status of results.
D/A Converter	A device to convert digital representation into an **analog** voltage or current level. Also called DAC.

Data	A general term used to denote any or all facts, numbers, letters, and symbols. It connotes basic elements of information which can be processed or produced by a computer.
Depletion Device	A type of **MOFSET** which is "on" when no input signal is present.
Development System	**Microcomputer** system complete with peripherals, memory and software, used to write, compile, run and debug application programs for one or more target **microprocessors.**
Die	A single square or rectangular piece of **semiconductor** material into which a specific electrical circuit has been fabricated. Plural is dice. Also called a chip.
Diffusion	A method of **doping** or modifying the characteristics of semiconductor material by "baking" wafers of the base semiconductor material in furnaces with controlled atmospheres or impurity materials.
Discrete	A semiconductor device containing only one active device, such as a **transistor** or a diode.
Dynamic RAM	A type of semiconductor memory in which the presence or absence or a capacitive charge represents the state of a **binary** storage element. The charge must be periodically refreshed.
ECL	Emitter Coupled Logic. A form of current-mode logic in which the output is available from an emitter-follower output stage.
EPROM	Erasable **PROM.** Similar to **ROM,** but enables the user to erase stored information and replace it with new information, when necessary. Most EPROMs are erased through exposure to ultra-violet light.
EAROM	Electrically Alterable **ROM.** A read-only memory whose contents may be altered on rare occasion through electrical stimuli.
EAPROM	Electrically-Erasable **PROM.**
Enhancement Device	A type of **MOFSET** which requires a control signal input to turn on the device. The device is "off" when no input signal is present.

FET	Field Effect **Transistor**. See **unipolar.**
FPLA	Field Programmable Logic Array. A **PLA** that can be programmed by the user.
Firmware	Software in hardware form. Refers specifically to computer **microcode** in **ROM.**
HMOS	High performance **MOS.**
Hybrid Circuit	Any combination of two or more of the following in one package: * Active substrate integrated circuit. * Passive substrate integrated circuit. * Discrete component.
I^2L	Integrated Injection Logic. A bipolar structure characterized by an integrated PNP load device and inverted operation of the NPN logic **transistor.**
Input/Output	Relating to the equipment or method used for transmitting **(I/O)** information into and out of a computer.
Integrated Circuit (IC)	A semiconductor **die** containing multiple elements that act together to form the complete device circuit.
LED	Light Emitting Diode. A semiconductor device that emits light whenever current passes through it.
LSI	Large Scale Integration. LSI devices contain 100 or more **gate equivalents** or other ciciutry of similar complexity.
LS TTL	Low-power Schottky TTL logic. The power dissipation of LS TTL is typically one-fifth that of conventional TTL.
Linear IC	An **analog** integrated circuit, as opposed to a digital integrated circuit.
MESFET	Metallic Schottky **FET.** A field effect transistor whose gate structure conists of a metallic Schottky barrier.
Microprocessor	Computer central processing unit on a single chip.
MOS	Metal Oxide Semiconductor. Devices using FETs in which current flow through a channel of N- or P- type semiconductor material is controlled by the electric field around a gate structure. MOSFETs are **unipolar** devices characterized by extremely high input resistance.
MOSFET	A type of Field Effect **Transistor.** See **MOS.**

MPU	See microprocessor.
MSI	Medium Scale Integration. ICs containing ten or more gate equivalents but less than 100.
Mask	A patterned screen, usually of glass, used to expose selected areas of a semiconductor (that has been covered with a **photoresist**) to a light source that causes polymerization.
Microcomputer	A **microprocessor** complete with stored program memory (ROM), random access memory (**RAM**), and input/output (I/O) logic. If all functions are on the same **chip**, this is sometimes called a **microcontroller.** Microcomputers are capable of performing useful work without additional supporting logic.
Microcontroller	See **microcomputer.**
Microelectronics	Microscopically small components or circuits made by means of photolithography techniques.
Micron	Synonymous with micrometer: one millionth of a meter.
Microprocessor	The basic arithmetic logic of a computer. See **CPU.**
Monolithic Device	A device whose circuitry is completely contained on a single **die** or **chip.**
PLA	Programmable Logic Array. A general purpose logic circuit containing an array of logic **gates** which can be connected (programmed) to perform various functions.
PROM	Programmable Read Only Memory. A read-only memory which can be programmed after manufacture by external equipment. Typically, PROMs utilize fusible links which may be burned open to produce a logic **bit** in a specific location.
RAM	Random Acess Memory, which stores digital information temporarily and can be changed by the use. It constitutes the basic storage element in a computer. Also called a read/write memory.
ROM	Read Only Memory, which permanently stores information used repeatedly - such as **microcode** or characters for electronic display. Unlike **RAM,** ROM cannot be altered.
SOS	Silicon-On-Sapphire. A faster **MOS** technology in which the silicon is grown on a sapphire **wafer** only where needed.

	Each device is thus isolated by air or oxide from other devices.
SSI	Small scale integration. **ICs** containing fewer than ten logic **gates.**
Schottky TTL	A form of TTL logic in which Schottky diodes are used to clamp the transistors out of saturation, effectively eliminating the storage of charge within the transistor... allowing increased switching speeds.
Semiconductor	A material with properties of both a conductor and an insulator. Common semiconductors include silicon and germanium.
Static RAM	A type of **RAM** which does not require periodic refresh cycles, as does **dynamic RAM.**
TTL (or T^2L)	Transistor-Transistor Logic.
Transistor	The basic solid-state device used to amplify or switch electrical current.
VLSI	Very Large Scale Integration. VLSI devices are **ICs** that containt 1,000 or more **gate equivalents.**
Wafer	A thin disk of semiconducting material (usually silicon) on which many separate **chips** can be fabricated and then cut into indivicual **ICs.** Also called a slice.
Word	A set of **binary bits** processed by the computer as the primary unit of information.

SOURCE: **STATUS '80,** Integrated Circuit Engineering Corp. (Scottsdale, Arizona, 1981), pp. 91-95.

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