Semiconductors:
From Manipulated to Managed Trade

Laura D'Andrea Tyson
and
David B. Yoffie

Working Paper 47
August 1991

This paper contains excerpts from a book by Laura D'Andrea Tyson entitled Who's Bashing Whom? Trade Conflict in High-Technology Industries published by the Institute for International Economics in November 1992. Parts will also appear in a book edited by David Yoffie on global trade and competition to be published by the Harvard Business School.

Work on this paper was supported in part by the Institute for International Economics, in part by the Harvard Business School, and in part by a grant from the Sloan Foundation to the Berkeley Roundtable on the International Economy.

The authors are grateful to expert research assistance by Julie Herendeen, Eric Vayle, and P. Konstantina Kiousis

I. Introduction

The semiconductor industry has never been free of the visible hand of government intervention. Competitive advantage in production and trade has been heavily influenced by policy choices, particularly in the US and Japan. Some of these policy choices, such as the provision of public support for basic science, R&D, and education in the United States, have had general, not industry-specific, objectives. But other policy choices, such as the provision of secured demand for industry output through military procurement in the US and through preferential procurement of computers and telecommunications equipment in Japan, have been industry specific in intent and effort. In short, the semiconductor industry has been an explicit target of industrial policy--whether in the guise of military policy in the US or in the guise of commercial policy elsewhere in the world--*wherever it has developed*.

Conditions creating advantage in this industry have been manipulated by policy, not inherited like features of the national landscape. Nor has trade in this industry ever been "free," in the classical sense. Rather it has been manipulated by a myriad of formal and informal policies affecting both trade and foreign investment flows. These policies have ranged from formal tariffs and quotas, to restrictive or promotional policies on investment flows, to preferential procurement arrangements. Over time, these policies have had powerful effects on the levels and directions of trade flows among nations.

Why has the visible hand been so omnipresent and forceful in this industry? The answer lies in its strategic significance in both the military and economic sense. The semiconductor industry was born out of the US defense effort to develop ever more reliable and sophisticated military equipment. Throughout the years, its military significance has never been doubted--advances in semiconductor technology have supported all of the major advanced weapons systems, including the smart bombs and Patriot missiles that had their spectacular debut in the Gulf War.

In contrast with the American emphasis on the military significance of the semiconductor industry, the Japanese, the Europeans, and the newly developed countries have focused on its commercial or economic significance. The governments of these nations have accorded the semiconductor industry special promotional and/or protectionist treatment in the anticipation of several kinds of economic benefits, including: more productive, higher-paying jobs for their workers; greater exports, as a result of an expanded national share of growing world markets; the development of an indigenous technological infrastructure with spillover benefits for other industries; and the provision of linkage externalities--lower-cost, higher quality inputs--for downstream user industries, like computers and telecommunications equipment, which are also thought to have long-term economic significance.

Despite a general liberalization trend around the world in many industries, national governments have not foresworn measures to support their semiconductor industries. The visible hand present at the industry's conception is still present long after the industry has reached maturity. Moreover, while government regulation has been widely discredited in many sectors, there is no presumption that the visible hand of policy in semiconductors will lead to lower economic welfare than the invisible hand of the market. Indeed, the presumption if anything, runs the other way. Increasing returns to scale, substantial learning curve economies, linkage externalities, and technological spillovers are not the stuff of perfect competition and market optimality.[1]

In this paper, we demonstrate how the visible hand of government has had a significant impact on the patterns of competition and trade in the semiconductor industry. We first examine how government policy encouraged the development of the industry in the US and how policies at home and abroad affected the trade and foreign direct investment decisions of American companies. There is nothing particularly surprising in this part of the story. A combination of factor endowments, technological skills and growing demand, all fostered by concerted government policies, gave American companies a competitive edge. Global trade patterns reflected the strategies of these companies as they attempted to gain global market share in the context of changing production conditions and changing policy environments. Given their substantial first-mover advantages and the characteristics of industry production, there was every reason to predict that the dominant position of US companies in the industry would be perpetuated over time.

This prediction, however, proved to be erroneous. And this brings us to the second part of our story: how a classic strategy of infant-industry protection and promotion "worked" to create a competitive Japanese industry capable of challenging the supremacy of American companies. What is surprising about this part of the story is not that the Japanese targeted the semiconductor industry for development or that they relied on protectionist policies to do so but that their strategy was so effective at realizing its objective--the creation of a competitive domestic industry.[2] We argue that a European strategy, similar in some respects to the Japanese strategy,

[1] The so-called strategic trade theory literature is full of theoretical demonstrations that promotional or protectionist policies under these conditions can improve economic welfare at home and reduce it abroad. Whether such policies pay off in practice is another question, since the theoretical assumptions behind these demonstrations are usually very restrictive. And the weight of the empirical evidence, albeit flawed by overly simple models and inadequate data, suggests that such policies often reduce national welfare. See J. David Richardson, "Empirical Research on Trade Liberalization with Imperfect Competition," OECD Economic Studies 12, (Spring 1989): 8-44.

[2] It is important to emphasize that the objective of Japanese industrial policy in the semiconductor industry, as in other industries targeted for development, was not consumer welfare. The Japanese government never asked itself whether the costs of the policies it pursued in terms of foregone consumer welfare or the opportunity costs

was singularly unsuccessful.

Barriers to both imports and foreign direct investment by American companies were a key ingredient of Japan's infant-industry policy. Initially, American companies tended to discount the significance of these barriers, treating them as mildly irritating rather than life-threatening. But as the protected Japanese market grew and as ominous evidence of the successful Japanese challenge mounted, American companies began a fifteen-year struggle to open the Japanese market and to deter predatory Japanese business practices through various trade policy initiatives.

This struggle reaped little in the way of real gains, and, by the early 1980s, the American companies watched in disbelief as the Japanese companies surged into the open American market. Finally, in a crisis atmosphere brought on by a sustained cyclical downturn in industry demand, an aggressive price war by the Japanese producers, and the exit of all but two merchant American companies from DRAM production, the US industry mounted a trade policy initiative that resulted in a major five-year trade agreement with Japan.

The third part of our story is an assessment of the effects of this agreement. Was the agreement a complete failure, as many observers have argued, or did it realize at least some of its objectives?[3] Our analysis indicates that the agreement had different effects on different segments of the industry. These effects in turn depended on the nature of competition within these different segments and on the nature of company strategies within these segments. The evidence indicates that contrary to popular belief the agreement was not ineffective at realizing many of its aims, including stabilizing the share of US producers in the global DRAM market, reversing the precipitous decline of the share of US producers in the global EPROM market, and increasing the share of US producers in the Japanese market. Nor did the agreement reduce competition across the board, as is widely believed. Instead, the effects on competition varied by industry segment and varied over time. On the other hand, the agreement generated significant profits for the Japanese companies, and the investment of these profits into capital and R&D strengthened their position in future rounds of competition.

---

imposed on other industries exceeded the benefits of its policies for the semiconductor industry. A study by Baldwin and Krugman which attempts to address this characteristically "un-Japanese" question concludes that infant-industry policies succeeded in gaining a share of the global 16K DRAM market for Japanese producers but only at the expense of a net reduction in Japanese economic welfare. Their findings while suggestive are not conclusive because they fail to incorporate the possible dynamic effects of a Japanese position in the 16K DRAM market on profits and technological externalities in future generations of semiconductor products and in systems products incorporating semiconductor technology. As a consequence, their measure of economic welfare includes only the extra profits generated in the 16K DRAM market itself. See Richard Baldwin and Paul Krugman, "Market Access and International Competition: A Simulation Study of 16K Random Access Memories," in Empirical Methods for International Trade, ed. Robert C. Feenstra (Cambridge, MA: MIT Press, 1988), pp. 171-97.

[3]See David Mowery and Nathan Rosenberg, "New Developments in US Technology Policy: Implications of Competitiveness and International Trade Policy," California Management Review (Fall 1989).

Although our story focuses on the influence of government policy on competition and trade, other factors play important supporting roles in the outcomes we observe. Our story concludes with a discussion of how one of these factors--corporate strategies--affects national trade patterns. Especially in recent years, as the industry has matured and as the market has segmented, the matching strategies of segment leaders have exercised ever more influence on trade patterns in three of the highest volume products--DRAMs, EPROMs, and microprocessors.

In addition, current trade patterns are affected by past decisions on foreign direct investment, especially those decisions made in the early stages of the industry when US companies still had a dominant position. Assembly and fab locations, reflecting industry conditions in the 1970s, continue to produce exports from countries like Malaysia, the Philippines, and Israel, resulting in trade patterns that do not seem "optimal" in today's world. Significantly, even though higher efficiency might be achieved at new locations, many companies have not treated their costs at earlier locations as sunk and have continued to rely on them.[4]

II. Industry Economics and The Evolution of Comparative Advantage:

II.1. The Ascent of the US Firms[5]

The modern semiconductor industry originated in the United States in 1959 with the invention of the integrated circuit (IC). The fact that the industry was born in the United States is not surprising. Indeed, it is consistent with theories of trade that emphasize two kinds of country-based variables--the availability of factors of production and the level of domestic demand. At the time, the US was the unparalleled leader in technological, scientific, and engineering capabilities--the single most important factors behind the development of the semiconductor industry and the driving force behind competition in the industry throughout the 1970s.

American leadership in these general capabilities was partly a reflection of America's policy commitment to scientific training and to funding basic research. This commitment in turn was reflected in a number of indicators of technological superiority, including R&D spending as a

---

[4]See Laura Tyson and Manuel Castells, "High Technology in the Changing International Division of Production: Implications for the US Economy," in The Newly Industrializing Countries in the World Economy: Challenges for US Policy, eds. John W. Sewell and Stuart K. Tucker (London: Lynne Rienner Publishers, 1989) for evidence from the automobile and electronics industries--that companies tend to upgrade their offshore investments rather than bring the production back home.

[5]For more comprehensive, in-depth studies of the evolution of the American and Japanese semiconductor industries, see Michael Borrus, James Millstein, and John Zysman, "US-Japanese Competition in the Semiconductor Industry," Policy Papers in International Affairs 17, Institute for International Studies, University of California, Berkeley, 1983; Michael Borrus, Competing for Control: America's Stake in Microelectronics (Cambridge, MA: Ballinger, 1988) and Clyde Prestowitz, Trading Places: How we Allowed Japan to Take the Lead (New York, NY: Basic Books, 1988).

percentage of GNP, engineering and scientific manpower as a percentage of the total labor force, and US dominance in world patents through the early 1960s.[6] In other words, US policy priorities nurtured the scientific capabilities that were the single most important factor advantage in the industry's birth and early evolution.

In addition to these capabilities, the US also had the demand conditions supportive of the semiconductor industry's development in the form of a secured defense market. In the early years of the industry, up to 100% of its output was purchased by the military, and even as late as 1968 nearly 40% was still claimed for military purposes.[7] In addition, there was a derived defense demand for semiconductor output from the military's large procurement of computer output throughout the 1960s.[8] Direct and indirect defense purchases reduced the risk of investment in both R&D and equipment by semiconductor producers who were assured that a significant part of their output would be sold to the military. The willingness and ability of the government to purchase chips in quantity at premium prices allowed a growing number of companies in the industry to refine their production skills and develop elaborate manufacturing facilities. These improvements resulted in a continuous increase in the number of elements contained on a single IC coupled with significant decreases in price. More than any other product in industrial history, the production of ICs benefitted from an amazingly steep learning curve. In 1964, a chip containing about 64 components was priced at around $32. By 1971, the price of a chip containing over a thousand components was about $1.[9]

The rule of thumb in the semiconductor industry was that costs generally fell 30% to 40% with every doubling in volume. Such steep learning economies occurred because semiconductor manufacturing routinely yielded more defective than sound chips. For complex new products, yields as low as 25 percent were quite common, while mature products might yield 90 percent. The need to raise yields led firms to manufacture "technology drivers." A technology driver was generally a high volume product that had a relatively simple design. When a firm mass produced a technology driver, it would hone its manufacturing skills, and then transfer its learning to more complicated, lower-volume, higher value-added devices. DRAMs were particularly well suited for this task because they had a less complex structure than other ICs, which allowed firms

---

[6]For comparative numbers on these and other indicators of US technological structure, see Richard R. Nelson, "US Technological Leadership: Where Did It Come From and Where Did It Go?" Research Policy 19 (1990): 117-132.

[7]Borrus, Millstein, and Zysman, "US-Japanese Competition in the Semiconductor Industry."

[8]For an in-depth study of DOD's involvement in the creation of the nation's semiconductor and computer industries, see Kenneth Flamm, Creating the Computer: Government Industry and High Technology (Washington, DC: Brookings Institution, 1988).

[9]David B. Yoffie, "Global Semiconductor Industry 1987," Harvard Business School Case, No. 9-388-052; Michael Borrus, Competing for Control: America's Stake in Microelectronics.

to distinguish quickly between a flaw in the design and a flaw in the manufacturing process. For particular products, other high volume ICs, such as EPROMs and static RAMs, could also serve as technology drivers.

Since American firms invented DRAMs, EPROMs, and SRAMs, the US industry enjoyed obvious first-mover advantages. In addition to learning economies, product cycles were quite long, so the returns to a first-mover position in a given product could be substantial. These profits in turn were an important source of funding to finance R&D and capital spending for the next product generation.

From its inception, the semiconductor industry has been one of the most R&D-intensive industries, with R&D expenditures averaging over 10% of revenues. It has also been a highly capital-intensive industry, with as much as 30% of sales spent on capital equipment. At the same time, variable costs have always been small and have declined over time. The basic inputs into semiconductor production are sand (silicon) and electricity. Distribution and transportation costs have been tiny (1-2%). The only significant variable costs have been labor costs for the final assembly of chips. And by the 1980s, variable labor costs could be largely automated away. Investment patterns in semiconductors have been lumpy, producing chronic booms and busts, with excess capacity emerging approximately every five years. The cyclical nature of the industry in conjunction with steep learning curves has promoted a practice of forward pricing. For example, industry leader Texas Instruments was well known in the 1960s and early 1970s for pricing well below costs in the early stages of a product to build volume, gain market share, and move down the learning curve. Such aggressive forward pricing reputedly had a severe impact on budding Japanese competition in the early 1970s.[10] By the early 1980s, American producers were sharply critical of their Japanese competitors for similar pricing tactics.

In addition to their first-mover advantages, US firms continued to benefit from the nation's commitment to R&D and its pool of engineering and scientific talent. Defense financed a large share of semiconductor R&D in the 1950s, directly through contracts and indirectly through premium prices for new devices. The government continued to pay for a large share of R&D through the early 1970s, providing roughly one-half of the total from 1958 through 1970.[11]

The history of the American industry through the mid-1970s is a history of product

[10]Interview with industry executive. "Pre-emptive price cutting," defined as reduction in advance of productivity improvements along the learning curve, was a TI strategy. It was TI, not the Japanese companies, who pioneered this strategy which for TI was made possible by relying on cheap second-source producers. Dieter Ernst and David O'Conner, "Competing in the Electronics Industry--The Experience of Newly Industrializing Countries," unpublished draft, OECD Development Center, Paris, 1991, p. 79.

[11]Kenneth Flamm, "Policy and Politics in the International Semiconductor Industry," a paper presented at the SEMI ISS Seminar, Newport Beach, California, January 1989. As late as 1958, a Congressional study found that federal funding paid for an estimated 85% of overall American R&D in electronics.

innovation driven by the entry of new firms. Between 1966 and 1972, for example, thirty new merchant firms entered the market. These firms were mainly formed by management and technical personnel who left established companies.

The US environment favored this pattern of competition in several ways. First, there were no policies or norms favoring permanent employment relationships between firms and their most valued employees. Indeed, the mobility of salaried employees has always been comparatively high in the United States. Second, the venture market supplied the financial capital necessary for entry on attractive terms. Third, the military, which remained the largest single consumer of leading-edge components throughout the 1960s, was willing to buy very expensive products from brand-new firms who offered the ultimate in performance in lieu of an established track record.[12] Fourth, some of the technological information required for successful operation was freely available through university and academic channels in which research continued to be funded by huge federal investments.[13] Indeed, the conditions of federal funding often required cooperation between industry and the supported university infrastructure. And, fifth, the US anti-trust environment worked to the advantage of the merchant firms and to the disadvantage of what might have been formidable vertically-integrated competitors, like IBM and AT&T.

As a result of a 1956 Consent Decree, AT&T was precluded from entering into competition in the emerging US semiconductor market and was required to give any company access to its technologies--at a royalty to be set by the Court, if the private parties could not agree. The entry of Texas Instruments, Fairchild, and others was greatly facilitated by the low-cost availability of AT&T's technological information. In the case of IBM, there was no court order precluding its competition in the market for semiconductors. But the credible threat of anti-trust action, combined with limitations on the profitability of semiconductors relative to system production and advantages to proprietary circuit development, kept IBM out of the developing merchant market.[14]

The US antitrust and patent environment also encouraged the flow of technological

---

[12]Indeed, Ernst and O'Connor argue that the Defense Department's support of small scale merchant firms was critical to semiconductor development in the US, since the Larger predominant firms in the 1950s were committed to the previous discrete technology based on germanium were extremely slow to adopt new circuit technologies based on silicon. Ernst and O'Connor, "Competing in the Electronics Industry--The Experience of Newly Industrializing Countries."

[13]For a complete discussion of the role of American universities in the creation and diffusion of technological knowledge, see David C. Mowery and Nathan Rosenburg, "The US National Innovation System," Consortium on Competitiveness and Cooperation, Center for Research in Management, Working Paper No. 90 3, University of California, Berkeley, September 1990.

[14]W. Edward Steinmueller, "Industry Structure and Government Policies in the US and Japanese Integrated Circuit Industries," Publication No. 105, Center for Economic Policy Research, Stanford University, December 1986.

information through the process of cross-licensing. Cross-licensing, which became a popular mechanism for avoiding lengthy and risky patent disputes among individual producers, promoted technological exchange and access among them.

As a result of all of the factors noted here--the availability of venture capital and a mobile technical labor force, the diffusion of technological information through open university research and cross-licensing, continued defense procurement, and the antitrust environment--the US semiconductor industry developed a distinctive character in which the largest producers of products sold on the market were not part of vertically-integrated systems producers but were so-called merchant firms, specializing in semiconductor products. This distinctive industry structure gave rise to distinctive industry strategies and forms of competition which were a source of vitality for the US through the mid-1970s.[15]

The potential sustainability of America's advantages in semiconductors was reinforced by the underlying economics. Learning curve effects were so significant that the US merchant industry remained relatively concentrated despite the proliferation of new vendors. In 1965, for example, the four largest merchants accounted for 69% of total industry shipments, and the eight largest accounted for 91% of such shipments. In 1972, even with significant new entry, the comparable figures remained high at 53% and 67%.[16] Furthermore, US industry leaders did not rest on their laurels; they sought to exploit their first-mover and country-based advantages by developing global strategies right from the beginning. Even the smallest semiconductor companies had international sales offices with exports that averaged about 20% of sales.[17] Since transportation costs were insignificant and since there were no credible foreign competitors, American companies aggressively exported their products to serve foreign markets.

Initially, global strategies focused on exporting, but foreign direct investment became more important over time. Foreign investment emerged for two reasons: first, US manufacturers sought to take advantage of low labor costs in Southeast Asia for the assembly of their products; and second, government protection limited market access in Japan and Europe. The shift to

---

[15]Porter emphasizes the effects of industry structure on distinctive national patterns of competitive behavior. See Michael Porter, The Competitive Advantage of Nations (New York, NY: Free Press, 1990). Although it is impossible to re-run history, it is nonetheless possible to speculate about what might have been the consequences for industry behavior had the US industry developed in a different environment--one more conducive to an industry structure more comparable to the Japanese. If the US industry had been dominated by large vertically-integrated producers, each of which produced chips for its own use and for sale to other users, it is likely that an even more concentrated industry structure would have developed. And this might have had two kinds of incentive effects. First, there would have been an incentive for these producers to sell to one another on terms that would prevent the entry of merchant competitors. And second, the incentive to compete by product innovation might have been reduced.

[16]Steinmueller, "Industrial Structure and Government Policies in the US and Japanese Integrated Circuit Industries."

[17]Borrus, Millstein, and Zysman, US-Japanese Competition in the Semiconductor Industry.

offshore assembly operations became important between 1964 and 1972, driven by the aggressive moves of firms in the increasingly competitive industry to compete on cost. The natural division of production among wafer fabrication, assembly, and testing allowed the assembly stage of production to be located at a different facility from fabrication and testing without any significant impact on learning economies. And the assembly stage required relatively low-skilled labor that was available abroad at a substantial wage discount--yielding up to a 50% reduction in total manufacturing costs. It was not for another decade that a high percentage of labor costs could be automated out of assembly.

The policies of both the United States and several newly industrializing countries also supported the offshore assembly strategy. Under items 807 and 806.3 of the US Tariff Schedules as amended in 1963, imported articles assembled in whole or in part of US fabricated components became dutiable only to the extent of the value-added abroad. This meant a substantial tariff break on the offshore assembly of chips. And beginning in 1967, the governments of Mexico, Taiwan, Singapore, Malaysia, and Korea, established "export platforms" to encourage direct foreign investment. These platforms offered a wide variety of inducements to such investment including tax-free exports, import tax reductions, and tax holidays. By 1978, the top nine US producers had 35 offshore assembly operations in ten developing countries in Latin America and Southeast Asia. By that time, more than 80% of the semiconductors shipped in the US were assembled and tested overseas, mainly in these countries (see Figure 1).[18]

The second type of foreign direct investment--point-of-sales affiliates--occurred mainly in Europe where high tariff rates (17% of value), preferential procurement procedures, and pressure by the European governments (especially the British and the French) encouraged such investment to serve growing European markets. The first major period of investment in Europe occurred between 1969 and 1974, by which time 46 affiliates, 18 of which were engaged in complete manufacturing operations, including fabrication, had been established.[19]

Tariffs, quotas, and other forms of border protection also encouraged US companies to consider foreign direct investment to serve the Japanese market. But the Japanese actively restricted such investment, in contrast to the Europeans who actively encouraged it. The Japanese strategy was avowedly one of import substitution through the creation and promotion of indigenous suppliers, while the European strategy was one of import substitution, at least in part, through substituting the local production of American companies for imports from them. The difference in these strategies is apparent in the numbers: Japanese companies have always supplied the lions' share (90%) of the Japanese marketplace, while American companies either

[18] Borrus, Millstein, and Zysman, US-Japanese Competition in the Semiconductor Industry, p.37.

[19] Kenneth Flamm, "Semiconductors," in Europe 1992: An American Perspective, ed. Gary Clyde Hufbauer (Washington, DC: Brookings Institution, 1990.)

through export or local production have supplied 50-70% of the European market, with the remainder supplied primarily by European companies.[20]

Only Texas Instruments, by refusing to license its key integrated circuit patents to Japanese firms and by petitioning the US government for trade protection based on patent infringement by the Japanese, was able to extract permission from the Japanese government to establish a wholly-owned manufacturing subsidiary in Japan prior to 1968.[21] The requirements posed by the Japanese government for investment by other US companies were so unattractive that few of them chose to exercise this option until after direct controls were abolished in 1978. By that time, for the reasons noted below, the incentives to invest in the Japanese market had been reduced for many American suppliers by the growing strength of Japanese firms.

II.2. Implications for Trade

The level and composition of US trade in semiconductors have been heavily influenced by the foreign direct investment decisions of American companies. Initially, the US ran a trade surplus in integrated circuits; but even while US firms remained dominant in the world semiconductor market, direct investment reduced net export earnings. The US began to run a trade deficit in integrated circuits as early as 1971. Although overall semiconductor trade showed a surplus through 1977. (Table 1) Initially, most US imports were assembled products from US affiliates located in the NICs; toward the end of the 1970s, however, the Japanese share of US imports began to rise dramatically. On the export side, most US exports of finished integrated circuits served four markets--Britain, France, West Germany, and Japan. US exports of unfinished circuits were primarily to five Southeast Asian assembly locations for final assembly and packaging. These products were then either re-exported to the US or to the other four final markets.

Consistent with these trade trends, by the late 1970s, an estimated 80% of the fabrication by US firms was still done in the US, and 20% was done abroad, mainly in Europe. The reverse numbers apply in assembly--about 80% of assembly by US firms was performed abroad and only 20% at home.[22]

---

[20]On the American share of the European market, see Flamm, "Semiconductors," 1990. On the American share of the Japanese market, see Borrus, Millstein, and Zysman, US-Japanese Competition in the Semiconductor Industry and Clyde Prestowitz, Trading Places.

[21]Initially, TI was only allowed to establish a 50-50 joint venture with Sony in 1968; four years later, Sony sold out to TI. MITI finally agreed to TI's request for a wholly-owned subsidiary only after TI threatened any Japanese exports of consumer electronics using TI's technology with an immediate patent infringement lawsuit. For more on the history of joint ventures in the semiconductor industry, see W. Edward Steinmueller, "International Joint Ventures in the Integrated Circuit Industry," Paper Series No. 104, Center for Economic Policy Research, Stanford University, September 1987.

[22]Borrus, Millstein, and Zysman, US-Japanese Competition in the Semiconductor Industry, pp. 35-42.

II.3. The Creation and Rise of the Japanese Industry

Overall, the history of the Japanese semiconductor industry is a successful and dramatic story of infant-industry promotion and protection. The overarching objective of government support was the creation of a competitive indigenous computer industry, with the creation of a competitive indigenous semiconductor industry as a means towards that end. In contrast to the US, where the government objective in these industries was a military one, in Japan the objective was purely commercial. Also in contrast to US support, which was designed to expand the technological frontier, Japanese support was designed as a catch-up effort.

From the inception of the industry in the 1960s, through the mid 1970s, the Japanese market was formally protected by a variety of measures. The government consistently rejected all applications for wholly owned subsidiaries and for joint ventures in which foreign firms would hold majority ownership.[23] It also restricted foreign purchases of equity in Japanese firms. High tariffs, restrictive quotas and approval registration requirements were used to control imports. Approval was also required for all patent and technical assistance licensing agreements. As a result of controls on the acquisition of foreign technology, MITI acted as a monopsonist buyer of such technology and also controlled its diffusion among Japanese firms.

These tight border controls held the US share of the Japanese semiconductor market substantially below what it was in the rest of the world. For example, by 1975 US firms had 98% of the US market, 78% of the European market, and only 20% of the Japanese market.[24]

Initially, the Japanese industry grew out of the application of transistors to consumer electronics products, followed by the substitution of semiconductors for such applications. Consequently, during this first phase production was dominated by a consumer-electronics orientation. In 1968, for example, 60% of all Japanese semiconductor production was in consumer electronics products. The Japanese continually lagged in the introduction of new products and in the most advanced semiconductor technologies.

Also, during this phase, the Japanese firms lagged behind in research. Through 1970, private company funding of R&D was not competitive with US funding. Indeed, in the early 1970s combined spending by Fujitsu, Hitachi, and NEC on semiconductor and computer R&D was less than Texas Instruments' R&D budget. Moreover, direct Japanese government subsidization of advanced IC R&D by Japanese firms was not significant, although a great deal of basic research was carried out in government and NTT laboratories.[25]

---

[23]Dennis Encarnation, "Investment and Trade," unpublished manuscript, Harvard Business School, Cambridge, MA, 1990.

[24]Borrus, Millstein, and Zysman, US-Japanese Competition in the Semiconductor Industry, p. 38.

[25]Borrus, Competing for Control: America's Stake in Microelectronics.

The 1970s marked the second phase of the industry's development in Japan. Gradually, in response to external pressure, the Japanese government phased out its formal trade barriers by 1976 and its formal foreign investment restrictions by 1978. At the same time, beginning in 1971, the government formally targeted a series of advanced technologies, including semiconductor technologies, and provided financing to stimulate their cooperative development with industry. Between 1971 and 1977, over sixty different projects received total financial support in the multi-hundred million dollar range in such areas as electron-beam exposure and large-scale integration (LSI) production equipment, discrete devices, basic materials research, and low-power, high-performance semiconductors.[26] (Table 2) All of these projects involved cooperation and co-financing by competitors in the pre-commercial stages of developing a new technology, stages where it is difficult to exclude others from the use of results and hence where the returns to knowledge-creation are not easily appropriable.[27]

These programs, along with related programs to support Japan's developing computer industry, succeeded in raising the value of more sophisticated integrated circuits as a share of total Japanese semiconductor output from 27% in 1971 to about 42% by the end of 1975. By 1976, the Japanese had developed a significant LSI capability, and they dominated their domestic market in all but the most sophisticated integrated circuit devices. They had also succeeded in raising their share of the domestic installed base of general purpose digital computers to over 60%.[28]

According to all accounts, they had realized this performance despite the fact that US semiconductor and computer products were available at lower prices, and at higher quality, capability and reliability levels than Japanese products. The "counter-liberalization measures" taken by the Japanese government to guarantee "that liberalization will not adversely affect domestic producers nor produce confusion" seemed to work. Despite the abolition of formal barriers, the foreign penetration of the Japanese market was held in check by a variety of offsetting policies, including R&D support, the government-sponsored formation of joint R&D and production ventures among the Japanese companies, preferential procurement policies--NTT would not buy any foreign systems products nor would it buy domestic systems products containing foreign semiconductors--and other administrative means, and by the purchasing decisions of the Japanese companies themselves.

Import penetration figures which showed little change throughout the 1970s and the premium charged by Japanese producers on their domestic prices compared to their export prices through 1978 are evidence of the continued closure of the Japanese market. This dual pricing

---

[26]Borrus, Millstein, and Zysman, US-Japanese Competition in the Semiconductor Industry.

[27]Note that although this research was precommercial, it was not generic--it was avowedly industry-specific, like Sematech.

[28]Borrus, Competing for Control: America's Stake in Microelectronics.

behavior came to a halt only after an investigation by the USITC confirmed dumping on the part of the Japanese companies.[29]

Of all the support programs of the 1970s, the most successful was the VLSI cooperative R&D program designed to help Japanese firms reach state-of-the-art production capabilities in the production of both memory devices and logic circuits. The Japanese strategy to move into the most sophisticated memory products reflected their aims and needs in telecommunications and computers. By the late 1970s, these needs could only be met either by producing more sophisticated memory devices like those which dominated the chip market in the US--devices in which the US firms had a commanding lead--or developing their own. Consistent with their infant industry approach, they chose the latter option.

By 1980, this option paid off. Although government support for the VLSI program was prematurely terminated in 1979 under political pressure applied by the US, by that time the program had helped the participating firms develop one micron device technology, submicron process technology and 64K dynamic random access memories (DRAMs). In essence, the program helped Japanese firms achieve technological parity with American firms in the production of the most sophisticated memory devices. Indeed, the Japanese firms were so convinced of the benefits of the VLSI program that they launched a private-sector extension to complete the research agenda without government help.[30]

The dramatic success of VLSI was partly a function of US mistakes. Leading American firms left a temporary void in the market in the mid-1970s, just as Japanese production was coming on stream. During the 1975 recession, American firms cut back on their capacity expansion plans. When the semiconductor market boomed in 1976-77, American companies were caught short, forcing their customers to search for other sources of supply and opening the door to new competitors. In addition, a technical disjuncture occurred in the mid-1970s, which only a handful of American firms exploited.[31]

Not only was the timing of the VLSI program fortuitous, but the choice of DRAMs proved critical. DRAMs are the largest volume commodity product of the semiconductor industry. They are a standardized good with almost perfect substitution capability among different

---

[29]Borrus, Competing for Control: America's Stake in Microelectronics, and Prestowitz, Trading Places.

[30]For more in-depth analyses of the VLSI program, see Flamm, "Policy and Politics in the International Semiconductor Industry," Borrus, Competing for Control: America's Stake in Microelectronics, and Thoms R. Howell, William A. Noellert, Janet H. Mac Laughlin, and Alan W. Wolff, The Microelectronics Race: The Impact of Government Policy on International Competition (Bolder, Colorado: Westview Press, 1988).

[31]There are two basic processes for making semiconductors: one is called bipolar, the other MOS--Metal Oxide Semiconductor. Bipolar was the older, more stable process used by most American firms since the 1960s. When MOS processes, which produced chips that consumed less power, became available, many American firms were slow to convert their factories.

producers producing at the industry norm. DRAMs, being standardized, were one of the easiest product lines for newcomers to break into because they required the least investment in support and distribution services. Proprietary design also offered little protection in DRAMs: intellectual property laws were fairly loose; plus, there were multiple ways to design a standard part. The most significant entry barriers into DRAMs were scale economics and the learning curve. Scale, in particular, became increasingly more important after the mid-1970s: while it cost only $3 million to build a fabrication facility in 1970, the price of such a facility approached $75 million in 1980. Moreover, since DRAMs were a commodity product, manufacturing costs mattered most. The way to drive down the cost of production was to improve yields (the number of good chips extracted from processed silicon wafers). Improving yields in turn depended on improving control over the manufacturing process--something which comes from experience, hence the reason for significant learning curve effects.

A policy of promotion and protection could help the Japanese companies gain the scale and technical experience they needed to become formidable competitors in the DRAM market. Protection allowed Japanese producers to reach minimum scale; promotion reduced the risk in making the big capital investments necessary to enter.[32] Such policies would not have been successful had the Japanese initially tried to target other semiconductor products, like microprocessors, where competition depends on proprietary design innovations, and where US companies had significant first-mover advantages because their products had already been adopted as the standards in important systems products. On the other hand, the targeting of DRAMs helped create knowledge in large-scale production process technology that had spillover benefits for Japanese companies in their efforts to break into other less standardized product lines in the 1980s.

The effects of promotion and protection in the Japanese industry must also be understood in the context of the industrial structure in which they occurred. The Japanese semiconductor industry is dominated by six multi-divisional, vertically integrated firms which manufacture electronics systems serving end-markets in consumer electronics, computers, and telecommunications equipment. These six firms are NEC, Hitachi, Toshiba, Fujitsu, Mitsubishi, and Matsushita. Together these firms form an even more concentrated oligopoly structure than that which prevails in the American merchant market. In the mid-1970s, for example, these six

---

[32]The policies of promotion and protection and the effects on Japanese producers were not unique to the semiconductor industry. For a general discussion and interpretation of Japanese industrial policy see Laura D'Andrea Tyson and John Zysman, "Developmental Strategy and Production Innovation in Japan," in Politics and Productivity: How Japan's Development Strategy Works, eds. Chalmers Johnson, Laura D'Andrea Tyson, and John Zysman (New York, NY: Ballinger Press, 1989). On Japan's promotion and protection of it's electronics industry, see also Marie Anchordoguy, "Japanese Industrial Targeting: A Challenge to Free Trade?" Working Paper, University of Washington, May 1990.

firms controlled 79% of domestic sales in Japan.[33]

Although all of these firms produce semiconductors for in-house purposes, a majority of their semiconductor sales are external. Approximately 20% of their production is consumed internally--and in memory devices, the figure is even lower. Thus the Japanese firms are neither captive producers, like IBM and AT&T, nor merchant producers, like Intel and National Semiconductor. Moreover, unlike the US merchant firms, the Japanese firms are large consumers of semiconductors, especially advanced integrated circuits. Together, they account for approximately 60% of total Japanese semiconductor consumption.

The structure of Japanese companies and their close relationships with one another and with various parts of the Japanese government, especially MITI, MPT, and NTT, have been important factors behind the continued difficulties of American producers to access the Japanese market. During the 1970s, American companies succeeded in penetrating the Japanese market primarily with advanced product innovations that Japanese firms were not yet producing. As Japanese suppliers became competent in the production of such devices, American suppliers experienced a decline in demand and saw their shares of the Japanese market level off or decline, even as Japanese demand grew.[34]

Through the mid to late 1970s, this pattern can be understood as the result of formal protectionist barriers--through various trade, investment, and technology barriers, the Japanese government acted as gatekeeper to restrict imports to those products not yet available from indigenous suppliers. After the liberalization of most of these barriers (significantly, preferential procurement through NTT remained in place), however, the pattern persisted. The most logical explanation for the persistence of this pattern lies in the incentives and business practices of Japanese firms. When the Japanese government ceased to act as formal gatekeeper, Japanese companies, perhaps encouraged by the Japanese authorities, took on the function in an informal way through their purchasing decisions.

To understand why and how the Japanese companies may have acted in this way, it is necessary to keep in mind their structure and the environment in which they functioned. Each of the six firms is part of a keiretsu--with implications for preferential sales arrangements among member firms and for restrictive distributional arrangements that block access to distributional channels by non-member companies. all participated in cooperative research and production

[33]Steinmueller, "Industry Structure and Government Policies in the US and Japanese Integrated Circuit Industries."

[34]This pattern has been observed in other Japanese industries and has been described as a moving band of protection--protection lasts only as long as is necessary to develop competitive Japanese suppliers--once such suppliers appear, imports fall sharply. In contrast to other countries, Japan is distinctive for its very low level of intra-industry trade--in product lines where its producers are competitive, it imports very little. See Johnson, Tyson, and Zysman, Politics and Productivity, for elaboration.

activities sponsored by MITI, activities designed to encourage specialization and communication and to discourage competition among the companies. All of the companies were active participants in the Electronics Industries Association of Japan--a legal trade association in which there was a long history of detailed exchanges of company production and sales information. Four of the six firms--Matsushita, Hitachi, Toshiba, and Mitsubishi--themselves had a long history of overt and clandestine methods for cartelizing the consumer electronics market in Japan and coordinating export efforts abroad;[35] while the two others--NEC and Fujitsu--were the beneficiaries of continued preferential NTT policies in the procurement of computers and telecommunications equipment.[36] And finally, all participated in a lax antitrust environment in which there was no credible sanction against cooperative or collusive behavior.

In light of these structural and behavioral features of the Japanese industry, one can interpret the continued difficulties of American companies to access the Japanese market even after formal liberalization in one of two ways. The first explanation is that there were undocumented and undetected formal efforts by the Japanese companies to cartelize the Japanese marketplace at the expense of foreign companies. Certainly, similar efforts involving some or all of the same Japanese companies have been documented in the television industry and in the office computer industries.[37] And the structure of the Japanese industry itself was certainly more conducive to cartel-like behavior than the structure of the American industry.[38] The second explanation is that because of the patterns of specialization, distribution, cooperation, and trust which had been fostered by the long period of protection and promotion and by the keiretsu system, the Japanese companies preferred whenever possible to buy from one another rather than from an outsider, even when that outsider was a new Japanese entrant and especially when that outsider was a foreign company supplying competitor firms, like IBM, in lucrative downstream markets.[39]

---

[35]For more on the history see Kozo Yamamura, "Caveat Emptor: The Industrial Policy of Japan," in Strategic Trade Policy and the New International Economics, ed. Paul Krugman (Cambridge, MA: MIT Press, 1986) and Pat Choate, Agents of Influence, Chapter 6, (New York, NY: Knopf, 1990).

[36]For the role of preferential procurement in the development of the Japanese computer industry, see Marie Anchordoguy, "Mastering the Market: Japanese Government Targeting of the Computer Industry," International Organization 42 (Summer 1988): 509-543.

[37]Kozo Yamamura and Jan Vandenberg, "Japan's Rapid Growth Policy on Trial: The Television Case," in Law and Trade Issues of the Japanese Economy, eds. Gary Saxonhouse and Kozo Yamamura (Seattle, WA: University of Washington, 1986).

[38]Such behavior was also made more likely by the exemption of the computer and semiconductor industries from the Anti-monopoly law.

[39]In a recent paper, Robert Lawrence provides econometric evidence demonstrating a link between the extent of keiretsu control of an industry and import penetration in that industry in the Japanese marketplace. Lawrence concludes that "producer keiretsu relationships are a significant barrier to the entry of foreign products into Japan." See Robert Lawrence, "Do Keiretsu Reduce Japanese Imports?" draft paper presented at Eight International Symposium of Japanese Planning Agency's Economic Research Institute, Tokyo, Japan, January 1991. For more

From the point of view of the effects on international trade and American producers, it is not germane whether the cartel explanation or what Ronald Dore calls the "relational handshake"[40] is the correct one. Access to the Japanese market by American companies continued to be effectively limited to those products not currently produced by their Japanese competitors. And the behavior generating this outcome was sanctioned, if not encouraged, by the relevant Japanese authorities.

The structure of the Japanese industry also had another behavioral effect which was devastating for their American competitors. Because of their vertical integration and keiretsu linkages, the Japanese companies had very deep pockets--they had access to relatively cheap and patient capital to finance massive investment spending even during periods of market slowdown and to incur sustained losses as part of an aggressive pricing strategy to increase their market shares. Only the two US merchants which were partly diversified, TI and Motorola, could afford to spend countercyclically or sustain losses for long periods of time. The consequences of these differences in industrial structure were first felt in the aftermath of the 1975 recession. While American firms, strapped for cash, cut capacity expansion during the downturn, Japanese firms cross-subsidized their investment, giving them their first opportunity to gain market share in the US. By 1983, the Japanese companies were out-investing the American companies, a trend which persisted through 1990.

The deep pockets of the Japanese companies also played an important role in their ability to mount an aggressive pricing war in the depressed market conditions of 1985-86.[41] This was one of the major factors behind the exit of seven out of nine American companies from the production of DRAMs by 1986 and the virtual domination of the latest generation of DRAM chips by the Japanese. As of 1986, the Japanese firms had a virtual monopoly in a key input for all of the systems applications in which they were becoming or hoped to become significant competitors.

Finally, Japan's successful thrust down the learning curve in DRAMs gave its companies another competitive advantage in the marketplace: by 1980, Japanese firms were delivering to their US and Japanese customers fewer defects per shipment, by an order of magnitude, than their American counterparts. Yet this should not be interpreted to suggest that Japanese firms had simply become "better." The initial Japanese advantage was derived from their targeting of

---

information on the nature of keiretsu ties see Michael Gerlach, "Keiretsu Organization in the Japanese Economy: Analyses and Trade Implications," in Politics and Productivity, eds. Johnson, Tyson, and Zysman.

[40] Ronald Phillip Dore, Flexible Rigidities: Industrial Policy and Structural Adjustment in the Japanese Economy 1970-80 (Stanford, CA: Stanford University Press, 1986).

[41] The Japanese pricing strategy was similar in many respects to the aggressive forward pricing strategy used by TI in the 1970s to gain market share. What distinguished the Japanese strategy was the ability of the Japanese companies to sustain significant losses because of their vertical structures and deep pockets.

DRAMs: using focused factories, Japanese firms had higher yields than the American merchants who manufactured a wider array of products. By the middle of the 1980s, however, the Japanese quality advantage was no longer significant. American firms responded to the competitive challenge, and defect rates delivered to customers were not appreciably different between US and Japanese suppliers by that time.

II.4. The Stagnation of the European Industry[42]

The European approach to the semiconductor industry was similar to the Japanese approach in one basic respect--the use of protection to promote national producers. European semiconductor producers were protected by a steep tariff of 17% that survived both the Kennedy and Tokyo Rounds of GATT tariff reductions; by rules of origin that effectively blocked the use of imported semiconductors in European electronics manufactures crossing the EC-EFTA boundary; and by informal non-tariff barriers, including preferential procurement practices, that encouraged European production by foreign producers to serve the European market. All of these protectionist practices were an important force behind the substantial direct investment by American producers in European production facilities.

Unlike the Japanese, the Europeans allowed--indeed encouraged--such investment as a substitute for imports. The explicit objective of Japanese strategy was the promotion of a Japanese industry, while the objective of the European strategy increasingly became the promotion of a European production base, regardless of ownership. The Japanese strategy closed the Japanese market to investment by US companies, thereby reserving domestic demand for Japanese companies, and forcing US firms to transfer technology to their Japanese competitors if they wanted to profit from growth in that market.

In contrast, the European strategy allowed American companies to earn a return by investing in European production facilities, without transferring their technological know-how to budding European competitors. Through such investment, American companies could pre-empt the developing European market for advanced products which European companies could not yet produce. Some observers believe that such investment was a key factor behind the failure of the European producers to gain a growing share of world markets.[43]

---

[42]For two complete discussions of the history of the European semiconductor industry see Michael Borrus, Competing for Control, Chapter 8 and Kenneth Flamm, "Semiconductors," in Europe 1992: An American Perspective, ed. Gary Clyde Hufbauer (Washington, DC: Brookings Institution, 1990). A similar position on the detrimental effects of American DFI on the European Semiconductor industry is taken by Ernst and O'Connor, "Competing in the Electronics Industry--The Experience of Newly Industrializing Countries," p.78.

[43]See, for example, the arguments by Giovanni Dosi in "Technical Change and Survival: Europe's Semiconductor Industry," Sussex European Paper No. 9, Sussex European Research Center, 1981. A similar position on the detrimental effects of American DFI on the European Semiconductor industry is taken by Ernst and O'Connor, "Competing in the Electronics Industry--The Experience of Newly Industrializing Countries," p. 78.

Another factor behind the weakness of European producers was the fragmentation of the large European market into much smaller national markets. This fragmentation eliminated the potential for European product specialization. Ironically, market fragmentation was encouraged by national policies that discouraged cooperation among European companies from different European nations while encouraging cooperation between such companies and American firms. As a result of such policies, US companies were able to operate in most of the major European countries, capturing the benefits of scale that were denied to their European competitors.

Europe's difficulties in semiconductors were also aggravated by the failure of its promotional policies in the computer industry. European governments protected national computer markets via high tariffs and promoted national champions via direct subsidies and preferential procurement. This strategy was a failure, and the European computer industry continued to lag well behind its US competitors.[44] In this respect, the European situation was similar to the Japanese one. Like the Europeans, the Japanese had targeted the computer industry and had encouraged their producers into a head-on competition with IBM. Both the European and Japanese strategies failed. But whereas the Europeans continued to target the computer industry directly, with relatively modest support for the semiconductor industry, the Japanese developed policies to promote the semiconductor industry directly as a means to build strength in the computer industry. It was only in response to the precipitous decline in the fortunes of the European semiconductor industry between 1975 and 1985, and the mounting challenge of the Japanese that the Europeans began rather belatedly to develop significant programs to support their semiconductor producers in the second half of the 1980s.

The weakness of the European computer industry meant that there was relatively little demand for the high-performance chips that drove technology development in the US. Instead, European semiconductor producers focused on products oriented toward the telecommunications and industrial markets where European producers remained strong. As a consequence, the European companies produced mainly for European users, with only minimal sales to the rest of the world. Indeed, the largest integrated national champions promoted through national policies, like Thomson and Siemens, were primarily interested in developing semiconductor capacities that served their internal needs and only secondarily interested in serving as commodity component producers for other users.

Concentrating on producing specialized proprietary chips in this sheltered environment meant that the European companies failed to develop state-of-the-art manufacturing skills that were critical to competitive success in commodity memory products. As these products became

---

[44]Many reasons have been suggested in the literature for the failure of the European strategy in computers. For a comprehensive discussion, see, Kenneth Flamm, Targeting the Computer:Government Support and International Competition (Washinton, DC: Brookings Institution, 1987).

the most rapidly growing segments of the global semiconductor market, the share of the European companies in this market fell precipitously, even within Europe itself. Flamm estimates that between 1975 and 1985, Europe's share of the global merchant semiconductor market fell by about 50%.[45] During this period, the share of European companies in the European market declined from 50% to 35%.[46]

II.5. *Outcomes of Different Development Strategies on Trade Flows and Market Shares*

The story of the spectacular rise in the world market share of the Japanese semiconductor industry and the offsetting fall in the world market share of the American semiconductor industry that began in 1978 and continued through 1985 is a well known one.[47] Seen in the light of the histories of manipulated trade told here, it is also an understandable one. Government policies shaped the domestic environments of US and Japanese firms and reversed the fortunes of once dominant American companies and their Japanese followers.

Japan's growing strength in IC production was reflected in Japan's trade and in the share of Japanese firms in world markets. In the US case, domestic firms retained leadership in ICs through the early 1980s, but suffered a growing trade deficit. This situation contrasted sharply with the Japanese experience: both government policies and firm export strategies produced increased share for firms and significant trade surpluses in ICs for Japan. Through 1978, Japan ran a net trade deficit in ICs. (Table 3) Thereafter, as Japanese 64K DRAMs began to hit the market, IC exports expanded rapidly. Japan's trade surplus in ICs grew from $43 million in 1978 to $2.3 billion by 1984. Imports from the US more than doubled during this time frame, while exports to the US grew by ten fold. Japanese firms focused their trade activity increasingly on the US market: chips destined for the US went from 24% to 45% of Japanese exports.

In the meantime, companies headquartered in the US (excluding captives) produced 55% of global semiconductor revenues in 1978 while Japanese companies produced 28% of revenues. By 1986, US firms captured only about 40% as Japanese companies claimed around 46%. (Table

---

45 Flamm, "Semiconductors," p. 236.

46 Borrus, Competing for Control, p. 196.

47 Following standard practice, all of the market share figures cited in the following discussion are based on dollar-denominated revenues for each country (based on the revenues of companies headquartered in that country) divided by total dollar denominated industry revenues. This practice means that market share calculations for individual countries are sensitive to changes in exchange rates. For example, the increase in the dollar's value against the yen between 1981 and 1985 by itself tended to increase the US market share and decrease Japan's market share. This implies that the decline in the US share during this period would have been even greater than the observed decline, and the increase in Japan's share would have been even greater as well had the dollar remained stable. The opposite is true for the 1985-89 period when the fall in the dollar's value tended to decrease the US share and increase Japan's share.

4) In 1985, the famous crossover occurred--the global share of the Japanese companies jumped ahead of the global share of the US companies. (Figure 2) Rankings of individual US companies dropped accordingly.[48]

US companies lost market share to Japan in almost all product lines. But the Japanese gain in share was most extreme in the DRAM market. In less than a decade, American companies went from market dominance to a minor role, as the Japanese gained ascendance and then dominance in this critical product (Figure 3). The crossover in DRAM market shares had already occurred by the end of 1981.

Slightly more than one-half of the overall decline in the US global market share in semiconductors between 1978 and 1985 was the result of faster growth in the Japanese market--a market which was served primarily by Japanese suppliers. The remainder of the decline in the US share largely resulted from the growing penetration of the US market by Japanese producers.[49] Between 1978 and 1985, semiconductor imports from Japan increased from under 5% of total US semiconductor consumption to 17%. In contrast, sales by US companies as a share of total Japanese semiconductor consumption were roughly stagnant--10% in 1978 and 9% in 1985.

---

[48]Our data is based only on merchant producers. Since no reliable production or revenue estimates exist, we exclude wholly captive manufacturers, the largest and most significant being IBM and AT&T. Including IBM and AT&T would change the absolute rankings (i.e. US shares of the world semiconductor market would probably be closer to those of Japan), but it would not alter the trends between the US and Japan. The best estimates suggest that IBM has been roughly the size of Japan's largest producer (NEC) and AT&T is roughly a quarter of that volume. Given the declining fortunes of both AT&T and IBM in their respective markets in the latter half of the 1980s, it is reasonable to assume that neither gained share over the time period.

[49]The Semiconductor Industry, a report of a Federal Interagency Staff Working Group, Washington, DC, November 16, 1987.

III. From Manipulated to Managed Trade: The 1986 US-Japan Semiconductor Trade Agreement

Had governments withdrawn from active participation in semiconductor markets after 1985, Japanese firms would probably have moved from a position of rough parity to virtual dominance. The changing economic structure of the industry made it even more likely that Japan's huge, vertically integrated firms would capture greater shares of the world market in the late 1980s and 1990s. The primary reason behind this prediction is that the rising economies of scale in production were making it almost impossible for small, merchant firms to invest in new fabrication facilities.[50] By 1985, a plant with minimum efficient scale was approaching $150 million in cost; by 1991 the comparable figure was $500 million. Any firm without stable cash flows from non-semiconductor businesses or a large volume commodity IC business, such as DRAMs, would have difficulty in keeping up with its larger, better financed Japanese competitors. Because of rising barriers to entry for new players and increasing mobility or re-entry barriers for existing players it is likely that the industry would become more concentrated and that barring a change in technology industry leaders (now in Japan) would gradually strengthen their hold on the market. Under this scenario, US and other firms might retreat to niches and survive, but they would have a declining impact on international trade.

The rapid decline of the US and the potential disappearance of Europe do not emerge so quickly because governments continued to shape the domestic environments and structure of international trade in semiconductors. As the title of this section describes, trade is no longer simply manipulated, as it was in the industry's first 20 plus years: since 1986 it has been actively managed.

The history of this management begins with the formation of the Semiconductor Industry Association (SIA) in 1977. Despite their fierce competition in the marketplace, American semiconductor firms had a variety of shared interests, especially concerning access to the Japanese market. Between 1979 and 1986, the SIA was highly successful in realizing many of its trade policy objectives.[51] It won an amendment to the Trade Act of 1974 which made clear that "denial of fair and equitable market access" could be the subject of a trade petition. It also successfully lobbied for the elimination of all semiconductor duties in the US and Japan and for the passage of the Semiconductor Chip Protection Act, which offered intellectual property protection to chip

---

[50]Charles Ferguson, a well-known critic of the US semiconductor industry makes this argument. In 1985, during visits to the Harvard Business School, he explicitly predicted that the US merchant industry would be bankrupt within three years. See Charles Ferguson, "From the People Who Brought You Voodoo Economics," Harvard Business Review 3 (May-June 1988): 55-62.

[51]David B. Yoffie, "Creating Political Advantage," Harvard Business Review (May 1988).

designs in the US and encouraged foreign countries to reciprocate.[52]

Battered by unprecedented short-term revenue losses and continued long-term losses in global market shares, the SIA finally submitted a formal Section 301 petition against unfair trading practices of the Japanese companies in June 1985. The petition was filed only after large users of semiconductors, such as IBM and Hewlett-Packard, indicated that they would not stand in its way. Like the US merchant semiconductor firms, many of the major users of semiconductors had come to believe that there was a lack of fair market access in Japan that ultimately worked to the detriment of American producers and users alike.[53]

Although there was industry agreement about the wisdom of a 301 petition against the Japanese, there was less agreement about the wisdom of pursuing anti-dumping relief. Dumping, in the traditional sense of higher prices charged by Japanese producers on domestic sales than on export sales, had been largely eliminated under US pressure after 1978. Thereafter, the dumping issue concerned whether the Japanese producers were selling below fair market value as determined according to US law by a "fair" markup over production costs. Although some US firms expressed interest in pursuing anti-dumping cases along these lines as early as 1982, others were concerned that successful cases would increase semiconductor prices in the US, thereby harming the industry's important users and weakening their support for a 301 petition. But concern over the price effects of an anti-dumping strategy quickly faded in the wake of aggressive pricing by the Japanese in the cyclical downturn of 1985.

Consequently, shortly after the 301 petition was filed, Micron Technology, one of the members of the SIA, charged Japanese firms with dumping 64K DRAMs. Then, in late September 1985, Intel, AMD, and National Semiconductor claimed that Japanese firms were dumping EPROMs, another memory device in which US producers still retained significant market shares (Figure 4). Finally, in an unprecedented move, the Department of Commerce "self-initiated" its own case, charging the Japanese firms with dumping 256K DRAMs.

The use of the nation's anti-dumping laws to stop an injurious price war made sense only for those products in which American companies hoped to continue to compete and for which there was compelling evidence of Japanese violation of American law. Thus, because most American merchant semiconductor companies, with the notable exception of TI and Micron, were not suppliers of 256K DRAMs, there was no private anti-dumping suit brought in this product

---

[52]There had been a long history of friction between the US and Japan on the patent issue. TI's applications for patents in Japan were unacknowledged by the Japanese until 1989. Since then Japanese firms have been paying TI significant royalties on these patents.

[53]When IBM was approached about the wisdom of a finding against the Japanese under the 301 petition, the IBM position was "Not only should you act, but you must act for the good of the nation." Reported in Prestowitz, Trading Places.

line.[54]

Instead, the large American merchants chose to emphasize the dumping issue in EPROMs. In late 1985, these producers, squeezed by their Japanese competitors in previous generations of DRAM products, hoped to prevent a repeat performance in EPROMs. They were justifiably concerned about such a performance in the wake of Hitachi's threat to cut prices in EPROMs in 10% increments until it won over the EPROM customers of Intel and AMD.[55] Whereas a successful anti-dumping suit in 256K DRAMs was deemed to be too late by most American companies, a successful anti-dumping suit in EPROMs was deemed to be early enough to be preventive without being costly to EPROM users.

After several months of negotiations between US and Japanese officials in response to the 301 petition and the anti-dumping suits, the US and Japan announced an accord on semiconductor trade in August 1986. The accord was a first in many respects. It was the first major US trade agreement in a high-technology, strategic industry, and the first motivated by concerns about the loss of high-tech competitiveness rather than concerns about employment. It was the first US trade agreement dedicated to improving market access abroad rather than restricting market access at home. Unlike previous bilateral trade deals, it attempted to regulate trade not only in the US and Japan but in other global markets. It was the first time the US government threatened trade sanctions on Japan for failure to comply with the terms of a trade agreement. Finally, the agreement signalled several major shifts in US trade policy that were to characterize the rest of the decade--the shift toward aggressive unilateralism, the shift toward conditional reciprocity, and the shift toward managing trade by results as well as by new rules.

The 1986 agreement on semiconductor trade (hereafter referred to as the SCTA) addressed both the issue of access to the Japanese market and dumping by Japanese firms in the US market. According to the agreement, the dumping suits and the section 301 case against Japan were suspended in return for stipulated actions by the Japanese government to improve market access for American companies and for the cessation of dumping by Japanese firms.

On the market access issue, the official agreement said that the government of Japan would provide sales assistance to help US and other foreign companies sell in Japan and would encourage long-term relationships between Japanese users and foreign suppliers. It also said that both governments anticipated improved opportunities for foreign sales in Japan. In a confidential side-letter to the official agreement, the Japanese government went further and stated that it

---

[54]TI was the logical company to initiate a dumping suit in 256K DRAMS. TI, however, produced most of its DRAMs in Japan and as a matter of corporate policy did not take active positions on trade disputes. In fact, TI had refused to join the SIA for almost a decade after it was formed.

[55]Quotation from Hitachi memo cited in SIA, A Deal is a Deal: Four Years of Experience Under the US-Japan Semiconductor Agreement, the Fourth Annual Report to the President, (November 1990).

"understood, welcomed, and would make efforts to assist foreign companies in reaching their goal of a 20% market share within five years." The 20% figure meant an effective doubling of the foreign share of the Japanese market.[56]

On the dumping issue, the SCTA suspended the EPROM and DRAM investigations without the imposition of duties (despite an assessment of dumping margins of up to 188% for individual Japanese suppliers). As part of the suspension agreement, the Japanese producers agreed not to sell their products at prices below their (average) cost of production, plus an eight percent profit margin, in the US market.[57] The Japanese agreed to have MITI monitor export prices on a wide range of semiconductor products, including EPROMs, 256K DRAMs, 8-bit and 16-bit microprocessors, to prevent Japanese producers from selling at less than fair market values in the US or in third countries. The Department of Commerce, in turn, was given the responsibility to calculate fair market values (FMVs) for each Japanese producer for each product based on that producer's costs and to monitor the production costs and prices of all Japanese products covered by the agreement. The US reserved the right to add or drop products from the monitoring arrangement in the future.

There were several distinctive features of the anti-dumping provisions of the SCTA. First, the agreement allowed for the monitoring of costs and prices on a wide range of products, including several which had not been the subject of the pending dumping investigations. It was anticipated that this arrangement would deter or prevent dumping of such products in the future. It had long been a complaint of the semiconductor industry and other industries that by the time a finding of dumping is actually made, substantial and irreparable harm has been done to American producers. The SCTA tried to address this complaint by heading off dumping before it occurred. Second, the agreement was structured to fit the global nature of competition in the semiconductor industry. Because American and Japanese producers competed around the world, an agreement which simply halted dumping by Japanese producers in the US market would leave American producers exposed to unfair Japanese competition in third country markets. If Japanese producers were able to offer more attractive prices in such markets, US and other consumers would switch their purchases there, and the US would become what the industry called a "high-price" island.

A third distinctive feature of the dumping provisions of the agreement was their focus on the cost and pricing behavior of individual firms. The SIA, cognizant of the concerns of its US

[56]Note that the SCTA set a share figure in terms of the nationality of suppliers, not where they were located. Thus, sales by American owned firms from any production location, including Japan, were to count in the calculation of the US market share.

[57]These pricing restrictions on the Japanese did not apply to their US production facilities. A similar exclusion was adopted by the Europeans in their pricing agreements with the Japanese in 1989 and 1990. The exclusion of local production facilities from the anti-dumping agreements was another factor encouraging the surge of Japanese investment on such facilities by the end of the decade.

customers about higher semiconductor prices, explicitly opposed both an import quota and a price floor as mechanisms for responding to Japanese dumping. The evidence indicated that there were significant differences among individual Japanese companies on costs. So the agreement was structured to allow low-cost Japanese producers to continue to compete on price with high-cost Japanese producers. From the US perspective, such competition would have two beneficial effects: it would limit any price increases resulting from the enforcement of the agreement; and it would discourage further expansion of capacity by Japan's high-cost producers, thereby making it easier for lower-cost American producers to win a share of the Japanese market.

IV. The Effects of the Agreement on Trade and Pricing

IV.1. Effects on Market Access

After 1986, Japanese firms had the benefit of the world's fastest growing domestic chip market. Just as Japanese firms realized a larger share of world production, Japan's share of world consumption exceeded that of the US and approached 40% by 1988. (Figure 5) In the absence of a trade agreement in such a scale sensitive business, limited access to the world's largest market (Japan) could significantly disadvantage US and European firms.

But did the market access agreement have any impact on US and other foreign-affiliated firms' exports to Japan? The quantitative evidence suggests that after the US government retaliated against Japan in March of 1987, market share started to rise (Figure 6); furthermore, our interviews have suggested, at least anecdotally, that government pressure on Japanese firms did improve the prospects for US exports to the Japanese market. As of the end of 1990, the foreign share of the Japanese market was approximately 13.35%, up from 8.5% when the agreement was signed, and at its highest level ever.[58]

The increase in share has been largely the result of concerted action by the Japanese semiconductor companies themselves to realize a 20% foreign market share in their own purchases. (As of this writing Hitachi, NEC, Mitsubishi Electric, Oki Electric, and Toshiba have already done so and Sony, Fujitsu, and Matsushita claim they are planning to do so.) The real effort by the Japanese companies to increase foreign access began only in late 1987, however, in response to continuous US pressure, with the formation of the EIAJ Users Committee, sixty major

[58]Note that given the way SIA measures market access, if a Japanese firm sells a packaged and tested product to an American firm, the chip is counted as a Japanese chip regardless of who fabricates the die, whose label is on the package, or who sells the part to the eventual customer. Consequently, any such sale would not be included in the calculation of foreign market share in Japan, even though such a sale brings some benefits to the American supplier. Also note that such transactions in which an American company is involved in the fabrication or sale of a chip in Japan have increased since the agreement as a result of alliances between US and Japanese companies, but such transactions are not counted in measuring US market share.

Japanese companies, including the Japanese semiconductor companies, each of which adopted a market access plan of its own. In addition, in 1988, the Japan Automotive Parts Industry Association began to explore its role in increasing purchases of foreign semiconductors. This effort by the Japanese companies to increase their foreign semiconductor purchases mirrored a larger national effort by the Japanese to increase imports of manufactured goods. Relevant Japanese authorities encouraged greater imports through beneficial tax treatment and jawboning. Both of these actions were responses to continued pressure by US trade negotiators for improved results on the US trade imbalance.

Although most of the increase in foreign share in semiconductors has been American, other foreign producers have also benefitted. The share of European, Korean and Taiwanese industries in Japan increased from .3% to .7% between the end of 1986 and the second quarter of 1990. This is a large percentage increase on a very small base.

American firms have also made a variety of efforts to improve their sales in the Japanese market since the signing of the SCTA. For example, in its 1990 report, the SIA shows that between 1986 and 1989, US suppliers added 30 sales offices to the 42 offices already in place. They also opened more than 16 new design centers--a fourfold increase--six new test and quality centers to a total of 18, and four new failure analysis centers to a total of 15. Overall, expenditures by US companies for personnel in Japan have increased by 32%, capital expenditures are up 162% and sales expenses have increased 86% since the agreement.[59]

It is interesting to note that most American companies do not seem to believe that direct foreign investment in Japan would solve the market access problem. While many US producers have chosen to invest or increase production in Europe in anticipation of increased protectionism, only a handful have invested directly in Japanese production facilities. Despite the conventional wisdom in Japan that foreign producers will remain marginal players in the Japanese market unless they have production facilities there, only a few American firms have chosen to build such facilities: TI, which operates three wafer fab, assembly and test complexes; Motorola, which has a wholly owned integrated facility and also a joint venture with Toshiba; Analog Devices, which operates an assembly and test plant; and LSI logic, which runs a front-end plant with Kawasaki Steel. The other major US merchant suppliers have concluded that their near-term sales prospects in Japan, despite the SCTA, do not justify the several hundred million dollars it would cost to build a front-end facility. Instead of building new production facilities in Japan, most American suppliers have preferred to bolster their investment for design, testing and sales--investments which are notably less expensive than investment in new production facilities.

Some American companies have complemented this strategy by forming alliances with

---

[59]SIA, A Deal is A Deal, pp. 4-15

Japanese firms to improve their access to the Japanese market. The most notable and significant example is the alliance between Motorola and Toshiba. Although this joint venture was in the works before the signing of the SCTA, it has been strengthened and expanded, in part, as a result of the incentives set in motion by the trade agreement. The alliance involves a far-reaching exchange in which Motorola has leveraged its technological strength in microprocessors to obtain a strong foothold in the Japanese DRAM market. As a result of the alliance, Motorola packages and markets DRAM dice manufactured by Toshiba and has acquired memory technology to produce 256K, 1M and 4M DRAMs, and 256K and 1M SRAMs. In return, Toshiba has received 8, 16, and 32 bit microprocessor technology from Motorola. Using the technology acquired from Toshiba, Motorola is now manufacturing its own 1M DRAMs in Japan and Scotland and has transferred the process to its Arizona facilities. Since withdrawing from the DRAM market in early 1985, Motorola has used its alliance with Toshiba to rebuild its DRAM market share, and DRAMs are now the company's largest revenue producing memory product.

The 20% target for foreign market share established by the SCTA side-letter was not realizable solely through the sale of memory devices. Consequently, the target assured that in addition to increased purchases of foreign memory devices, Japanese companies would also have to design proprietary foreign devices into their electronics systems products. The market trend toward ASICs, a segment in which there are many leading-edge American companies and products, provided an opportunity for American firms to be designed into systems which cannot easily be replaced. In addition, such design-in relationships require close relationships between Japanese systems engineers and foreign semiconductor engineers. Such relationships have been encouraged by the pressure on the Japanese companies to find ways to increase their purchases of foreign semiconductors. The design-in of ASICs is an especially important route for the entry of American products into Japan's huge consumer electronics market.

Finally, it is important to emphasize that sustained US pressure, backed up by the threat of further trade action, seems to have played a critical role in the increase in US market share beginning in mid 1989. Prior to that point, American firms simply recaptured the roughly 10% of the Japanese market they had traditionally supplied before the 1985-86 slump. Tough talk by the Bush Administration in 1989 and SIA lobbying efforts spurred Japanese manufacturers into action. Fears that the SIA might get the White House to make semiconductors a US trade priority under the Super 301 provision of the 1988 Trade Act led to a series of initiatives to facilitate the development of long-term relationships between US suppliers and Japanese users. These initiatives, complemented by the efforts of American suppliers to expand their Japanese sales, paid off in a dramatic increase in US share between mid-1989 and the end of 1990.

IV.2. Effects on Pricing

In the first few months after the conclusion of the agreement, prices of semiconductor memory devices exported from Japan jumped sharply. US customers reported that prices of 256K DRAMs had risen anywhere from two to eight times the pre-agreement price. Shortly thereafter, the Commerce Department adjusted its FMV calculations on the basis of more recent cost data, and by early 1987 US customers were reporting that the revised FMVs were not too far off what the market itself would have produced.

Sustained price increases came only after the imposition of sanctions on Japanese companies for failure to comply with the provisions of the agreement. By March 1987, SIA members were convinced that the Japanese were violating the agreement by selling below FMVs in third markets and by failing to increase purchases from US producers. Evidence of the former came from documentation of sales at less than FMVs by Japanese companies in the Far East.[60] Evidence of the latter came from the fact that there had been no increase in the US share of the Japanese market since the signing of the agreement.

In an unprecedented move, the Administration responded to charges of violation with a decision to impose sanctions on the Japanese producers. It did so in a highly charged atmosphere in which both Houses of Congress voted to encourage the Administration to apply sanctions, and in which the Defense Department issued a study that pointed with alarm to declining US competitiveness in semiconductors and the semiconductor equipment industry.

Shortly after the imposition of sanctions, the prices of DRAMs began what was to become a precipitous increase lasting through the end of 1988. All of the available data series show an unprecedented and sustained increase in 256K DRAM and 1M DRAM prices beginning shortly after the sanctions were imposed. (Table 5) 1987 was the first year in the history of large-scale DRAM production during which the average price per bit of memory increased. DRAM prices jumped again in 1988 and remained far in excess of reasonable estimates of FMVs for the leading Japanese producers throughout 1988 and 1989. DRAM prices in Japan, although also slightly higher than before the agreement, were noticeably lower than prices in the US, Europe, and East Asia through the middle of 1989 (Table 6 and Figure 7).

The most dramatic price increases occurred in 1988, when spot prices for 256K DRAMs tripled over a four month period,[61] and American consumers reported significant difficulties in obtaining adequate supplies at any price.[62] The price hikes and supply interruptions caused

[60]SIA, A Deal is A Deal, p. 60.

[61]For detailed price information, see Kenneth Flamm, "Measurement of DRAM Prices: Technology and Market Share," Working Paper, Brookings Institution, November 1990.

[62]For anecdotal evidence on these difficulties, see SIA, A Deal is A Deal, and Charles Ferguson, "DRAMs, Component Suppliers, and the World Electronics Industry: An International Strategic Analysis," VLSI Memo 89-554, MIT, August 1989.

several US system vendors to ration memory shipments, delay new product introductions, and increase prices.[63] The increase in spot prices for DRAMs was especially severe--spot prices rose three to six times higher than long-term contract prices, with the result that the effective price paid by any consumer depended heavily on the percentage of demand they had to purchase on the spot market.

By early 1989, most major US consumers reported that they could obtain adequate supplies, and the gap between spot and large contract prices had disappeared. By mid-1989, the regional price differentials had also disappeared--prices in Japan were roughly equal to prices in other major markets. In addition, 256K and 1M DRAM prices were trending downward, in part in response to the introduction of the next generation 4M DRAM device, whose price had fallen continuously since its appearance in the second half of 1988.[64]

But the prices of all DRAM products remained high enough to yield hefty profits for their Japanese producers. Flamm estimates that higher prices meant about $4 billion of additional annual profits on global DRAM sales on the order of $10 billion in 1988. Since the Japanese had the lion's share of the DRAM market, they earned the lion's share of these so-called "bubble profits." The two remaining American DRAM producers, TI and Micron Technology, also profited substantially from the surge in demand for DRAMs. According to one Wall Street semiconductor analyst, between 30% and 40% of TI's semiconductor operating profit in 1987, and as much as 60% in 1988, was attributable to DRAM sales. Micron, which specialized in DRAM production, enjoyed a 6-fold rise in revenues between 1986 and 1988 and became profitable that year, for the first time in three years, as a result of DRAM demand.[65] The bubble profits of the Japanese, in turn, were ploughed back into R&D and investment. As a consequence, the gap between capital and R&D spending by Japanese companies and American companies expanded still further. By 1988, Japanese capital spending was nearly $2 billion higher than that of the US.

63 Flamm reports that as a result of the increases in semiconductor prices, computer prices were affected in 1988 and 1989. See Flamm, "Measurement of DRAM Prices."

64 A recent study argues that by the end of 1989, the average price per bit for DRAMs was on its long term trend, estimated by the 1974-84 relationship between the average price per bit and cumulative bit consumption. This estimated relationship in turn is interpreted as the "long-term learning curve" for DRAM production. The study also concludes that compared to this relationship prices were excessively low between 1984 III and 1987 II presumably due to dumping and excessively high between 1987 II and 1989 III presumably due to the price effects of the trade agreement. Although these conclusions are provocative, they depend on the assumption that the estimated learning curve relationship for 1974-84 is the appropriate standard of comparison. Since the Japanese did not become a major competitive force in the industry until 1980 and since their learning curve gains were probably more dramatic than the American gains, it is not clear that the 1974-84 relationship is the appropriate standard by which to judge 1984-89 price trends. For more detail, see "The Impact of the 1986 US-Japan Semiconductor Agreement on DRAM Prices," a study prepared for the SIA by Technecon Analytic Research, Washington, DC, January 1991.

65 The rough calculations used to estimate these profit figures were derived from the models of Daniel L. Klesken, Ph.D., semiconductor analyst at Prudential-Bache.

and the R&D spending of the top 5 Japanese companies exceeded the R&D spending of the top 5 American merchant firms by about $1.5 billion.[66] Thus, the agreement had the perverse result, from the American perspective, of disproportionately strengthening the Japanese companies for future rounds of competition in new products.

Did the SCTA cause the dramatic price increases in DRAMs and the huge additional profits for the Japanese producers that occurred after the middle of 1987? Most critics of the agreement think so. But the chain of causality between the agreement and the price hikes is not as simple or as direct as many observers believe. First, higher DRAM prices after 1987 were partly the result of a cyclical upsurge in demand stemming from growth in the computer industry. And to some extent they were also the result of unanticipated technical difficulties associated with bringing new 1M supply capacities into production.

Second, contrary to what many have asserted, the SCTA did not establish an overall price floor. Indeed, US negotiators were careful not to do so. The whole idea of calculating FMVs for individual Japanese companies was to allow the more efficient ones to sell at lower prices than the less efficient ones, thereby encouraging competition among the Japanese suppliers, and preventing an overall price floor.

Third, throughout 1989 DRAM prices remained far above the individual FMVs for most, if not all, of the Japanese producers, even the high-cost producers like OKI. And, fourth, as is demonstrated below, similar anti-dumping provisions on EPROMs in the SCTA did not have similar effects on world prices. Overall, the evidence indicates that the SCTA played a precipitating role in causing higher DRAM prices by promoting cartel-like behavior on the part of the Japanese firms, behavior that was encouraged and facilitated by the actions of MITI.

There is little doubt that shortly after the negotiation of the agreement and with renewed vigor after the imposition of sanctions in the spring of 1987, MITI imposed production and investment cutbacks and export controls on all Japanese producers.[67] Indeed, Flamm describes a four-part program of export controls that included export allocations and an effective minimum price floor on DRAM exports for different regional markets.[68]

If MITI had been acting simply to enforce the provisions of the trade agreement, it hardly needed to restrict production and exports to such an extent that prices would soar above the FMVs

[66]National Advisory Committee on Semiconductors, "A Strategic Industry at Risk," a report to the President and the Congress from the National Advisory Committee on Semiconductors, Washington, DC, November 1989, pp. 10-11.

[67]It is important to emphasize that TI's Japanese operations were covered by these MITI guidelines.

[68]MITI's attempts to control investment production and exports are described in detail in Flamm, "Policy and Politics in the International Semiconductor Industry" and "Measurement of DRAM Prices: Technology and Market Structure." A 1988 GATT panel ruling in response to a complaint by the European Community found MITI's system of production and export restrictions to be impermissible under GATT law, and it was formally terminated.

of the highest-cost Japanese producers. So either MITI made a mistake in its forecasts, with the result that prices vastly overshot the levels required by the SCTA, or there must be another explanation behind the observed trend in DRAM prices. Since MITI was making accurate forecasts of semiconductor production, investment, and domestic demand every three months,[69] it is hard to swallow the mistaken forecast explanation of pricing developments. A more compelling explanation, and one consistent with the history of MITI's continuous involvement in the industry since its inception, is that MITI worked with the firms to encourage cartel-like behavior that benefited all of them.

According to this explanation, MITI acted as an agent to facilitate cooperation among the Japanese firms to reduce US-Japan trade friction, but it did so in ways that would best serve the interests of the Japanese industry over the long run. And it did so in ways that were characteristic of its approach to industries experiencing losses--it stipulated production and investment cutbacks to remove "excessive competition" while allowing the weakest domestic firms to continue to survive.

Although MITI's actions facilitated greater cooperation among Japanese companies, their behavior suggests that they themselves came to see the attractions of such cooperation. Certainly, the dominance of these companies in global DRAM supply made a cooperative outcome feasible. There are several clues indicating cooperative behavior on the part of the Japanese producers in 1988 and 1989. In 1988, Japanese producers began to assert that a new pricing rule prevailed in the semiconductor industry. According to industry spokesmen, DRAM prices for each previous generation of memory device had tended to decline asymptotically toward the $3 level, as mass production of that generation peaked--the so-called "pi-rule" of pricing. In future generations of products, however, the Japanese contended that the so-called "bai-rule" would apply, meaning that every new generation of product would approximately double in price as mass production peaked.[70]

Other clues of cartel-like behavior in 1988 and 1989 include continued restraint on investment in 1988 despite huge inventory rundowns, higher prices, higher profits and surging demand; and repeated comments by Japanese industry spokesmen about the value of cooperation and about the desirability of avoiding the kind of "excessive competition" that had resulted in huge losses in 1985 and 1986. In product lines in which they now dominated, Japanese producers seemed to be behaving like profitability mattered more than market share.[71] And higher DRAM

---

[69]Evidence on the precision of the MITI forecasts is presented in Flamm, "Policy and Politics in the International Semiconductor Industry" and Ferguson, "DRAMs and the World Electronics Industry."

[70]For a discussion of these pricing rules of thumb, see Japan Electronics Almanac (Tokyo, Japan: DEMPA Publications, 1989).

[71]This arguement is also made by Fergeson in "DRAMs and the World Electronics Industry."

prices certainly meant higher profits. In 1989, for example, one-half of Toshiba's total profits came from its semiconductor division.[72]

Probably the most telling evidence of cartel-like behavior came at the end of 1989 when, in response to weakening demand and prices, Toshiba, the acknowledged production, cost, and price leader in 1M DRAMs, announced its decision to cut production, prompting similar announcements by all of the other Japanese producers on the same day. At the time of these announcements, DRAM prices were still significantly higher than their average costs of production (and dramatically higher than their marginal costs of production) for the leading Japanese producers. Yet rather than cut prices to sell more and gain market share at the expense of higher-cost producers, the low-cost producers chose to cut production--hardly the outcome one would expect in a competitive market.

It is important to emphasize that a price-cutting strategy was not ruled out by the SCTA, since the FMVs for the low-cost producers were still significantly below the prices they were charging. According to an estimate by Flamm, and consistent with SIA data (Figure 8), Toshiba's price of $9 for a 1M DRAM in December 1989 compared to an upper bound estimate of $5 for Toshiba's FMV.[73]

What, then, was the role of the SCTA in getting the Japanese companies to behave in more cooperative ways? Here there can be no conclusive answer. Perhaps even in the absence of the trade agreement these companies would have realized the extent of their market power and would have started to behave more cooperatively, since they had succeeded in driving out American competition. Certainly, their keiretsu structure, the absence of credible antitrust enforcement, a long history of cross-share holding, shared R&D efforts, and other cooperative links between the particular Japanese firms in question, and the fact that such firms competed with one another in a variety of other downstream systems markets made a cooperative outcome more likely. And certainly more likely than it would have been if the tables had been turned and a small number of American firms had dominated DRAM production. In such a case, the responsible American government agencies would have actively discouraged cooperative behavior--a glaring contrast with how the responsible Japanese government agencies behaved.

On the other hand, the timing of the appearance of cooperative behavior on the part of the Japanese companies, following so closely upon the sanctions imposed by the trade agreement, suggests an alternative explanation. This explanation, consistent with the theoretical literature on the effects of trade restrictions on company strategies in imperfectly competitive industries, sees

---

[72]Estimate reported by Hajime Karatsu to the National Research Council, June 1991.

[73]Reported in telephone interview with Flamm in January 1990.

the trade agreement as an external threat or prod that precipitated a change in industry behavior.[74] It is difficult to realize a collusive arrangement in a heavily concentrated industry even when such an arrangement works to the benefit of all of the players. But external pressure may encourage or even necessitate such an arrangement on a temporary basis, and if the firms see the benefits to be had,they may continue to behave cohesively even after this pressure has been removed.[75]

It is important to emphasize the role of market power in the choice of the cooperative outcome in DRAMs. In EPROMs, where several American companies still retained significant shares of the world market at the time the trade agreement was signed, the outcome was very different. According to some industry observers, Japanese firms became noticeably less aggressive in seeking market share across the board in EPROMs after the agreement.[76] After a brief increase in prices in the second half of 1987, the prices of 256K EPROMs were stable during most of 1988 and began to fall sharply by year's end, while prices of 1M EPROMs fell throughout 1988 and 1989 (Table 7). During much of the period, EPROM prices in the US and Europe were actually lower than they were in Japan. (Table 8) There were no shortages in EPROM supplies reported by American or other buyers, and American EPROM suppliers, like Intel, asserted that EPROM prices never significantly rose above marginal costs because of competitive market conditions. Finally, MITI acknowledged that it could not control the supply of EPROMs, as it could the supply of DRAMs, because it had no influence over the production and investment decisions of global players who were not Japanese.

The divergence of results in DRAMs and EPROMs helps to illustrate how government policy can affect trade in high technology industries. It is especially important for understanding differences between national oligopolies and cross-national oligopolies. Because of significant internal economies and dynamic feedback effects in production, the semiconductor industry is inherently oligopolistic. Moreover, because technological and capital costs of entry have risen sharply over time,[77] the market power of incumbent firms has been increasing.

Whether potential market power is exercised, however, depends on the ability of

---

[74] See, for example, Kala Krishna. Trade Restrictions as Facilitating Practices," Journal of International Economics 26 (1989): 251-270 and Avinash Dixit, "Optimal Trade and Industrial Policy for the US Automobile Industry," in Empirical Methods for International Trade, ed. Robert Feenstra (Cambridge, MA: MIT Press, 1988), pp.141-165.

[75] The interpretation that the SCTA was the prod behind temporary collusive behavior is consistent with recent evidence of a developing price war among Japanese firms. Slackening demand in 1990 and greater competition from Korean suppliers has led Japanese firms to slash prices of 1M, 4M, and even 16M chips to gain market share at one another's expense.

[76] Based on an industry interview. It was further suggested that Hitachi, the number 2 firm in EPROMs in 1985, dropped out of the market by the end of the decade partly due to a loss of "face" associated with its infamous memo on predatory pricing.

[77] Dataquest estimated that output from a single fab had to achieve six percent world market share in order warrant construction in the 1990s.

individual firms to commit to a cooperative strategy. For a variety of reasons, such a strategy seems more likely to emerge when an industry or segment is dominated by a small number of Japanese firms as the semiconductor industry was in the mid-1980s. First, there is no credible threat of antitrust prosecution. Second, information among firms is regularly exchanged through a number of publicly sanctioned channels, including industry associations, MITI panels, and government-organized and sponsored R&D projects. Third, because most large Japanese firms are members of large business groups, they compete with one another in a variety of product markets. And the greater the extent of multiproduct competition, the greater the long-run costs of deviating from a cooperative strategy in a particular product line.

Fourth, because of their financial structure, Japanese firms can credibly threaten to lose money for a substantial period of time to deter the entry of new competitors into an industry they dominate. Thus, all other things being equal, a Japanese oligopoly is likely to be more cooperative than an oligopoly composed of American or other companies with different financial structures.

On the other hand, a collusive or cooperative arrangement in a Japanese oligopoly, like such an arrangement in most oligopolies, is inherently unstable and can quickly dissolve under changing market conditions. This now appears to be the case in the Japanese memory oligopoly. Slack demand, the growing threat of Korean suppliers in 256K and 1M chips, and the jockeying for position in new 4M and 16M generations have undermined the ability of the Japanese industry to realize a collusive outcome. Prices of all memory devices have fallen precipitously since September 1990. As of mid 1991, the price of 4M DRAMs is too low to recoup the cost of new production lines needed to make them. As long as the US does not act to force the termination of a price war among Japanese suppliers, prices may decline still further and Japanese suppliers will run hefty losses as long as global demand remains soft.

IV.3. Effects on Market Shares[78]

Although still one of the highest technology industries (as measured by R&D as a percentage of sales), by 1991 the semiconductor industry was relatively mature: growth had slowed and radically new product introductions (like the DRAMs, EPROMs, and microprocessors of the 1970s) had become few and far between. One consequence of this maturity was that it was

[78]In response to the claim that most of the decline in the global market shares of US producers during the 1980s was simply due to exchange rate changes, a recent study examines what would have happened to these shares if exchange rates had been unchanged. The study concludes that more than 70% of the decline in the global market share of US producers and more than 60% of the increase in the global market share of Japanese producers between 1982 and 1989 was the result of "real" changes in their competitive positions, not the result of calculating shares in terms of a declining dollar. See William Finan and Chris Anderson, "The Effects of Exchange Rates on Semiconductor Market Share," SIA, January 1991.

becoming less appropriate to describe semiconductors as a homogeneous industry and more important to define trade and market leadership according to segments.

Perhaps the most positive effect of the SCTA was in EPROMs: the US share in the global marketplace grew from 42% in 1985, prior to the signing of the agreement, to 53% in 1989 (Figure 4). Preliminary estimates for 1990 show a continued increase in the US EPROM share. The share of Japanese firms dropped by 15 percentage points. By 1988, the US world market share exceeded the Japanese share in EPROMs. These trends were a sharp reversal of the trends in play before the agreement when the US was losing share in EPROMs while the Japanese were gaining rapidly. Japanese firms have also increased purchases of US EPROMs as part of their market access efforts.

In the meantime, the EPROM market has become less concentrated since the agreement (the C4 ratio declined from 59% in 1985 to 53% in 1990). American firms, especially AMD, National, and TI, as well as the European firm, SGS-Thomson, view EPROMs as an important technology driver which they should not cede to their Japanese competitors. Perhaps it is ironic that part of this managed trade agreement stimulated more competition in EPROMs and made the market less profitable over the long run for all participants.[79] The trade agreement may have had yet another perverse effect on the EPROM segment: although the SCTA seems to have facilitated a less aggressive Japanese strategy towards broad market domination, it may have stimulated Japanese firms to focus their investment only at the high end of EPROM performance. While Japanese firms have largely withdrawn from lower density (256K and under) EPROMs, they have been the most aggressive in the 1M EPROMs and new products called flash memory. Although two American firms continue to lead in that category (Intel and AMD), the Japanese had gained approximately 45% of the market in 1990 compared to America's 41% (Figure 9).

The EPROM experience stands in sharp contrast to DRAMs. In DRAMs, the US share stabilized at 16% after 1986 (Figure 3). Stabilization of the US share in part reflects investment by Micron and TI, the two firms which stayed in DRAM production through 1986, and the re-entry of Motorola. Except for Micron which invested solely in the United States, more than 80% of DRAM capacity expansion projects by American producers have occurred abroad, primarily in Japan and Europe. For example, Motorola has re-entered DRAM production as part of it alliance with Toshiba. Motorola licensed some of its key technology to Toshiba in order to obtain from Toshiba DRAM technology necessary for its re-entry, and now relies heavily on the joint venture for DRAM production. Toshiba also made market access commitments to Motorola as part of this agreement. TI has expanded DRAM capacity in Japan, Taiwan and Italy, in the latter two

[79]According to the manager of one of the leading EPROM manufacturers, firms were unlikely to break even in EPROMs in 1991 with less than 10% of the market. If this calculation was correct, only the top four firms were breaking even.

instances in response to special government incentives encouraging such investment.

If one looked only at industry structure variables or country-based variables, like factor endowments, Japanese firms should have maintained their oligopoly of the DRAM market: even though prices bulged in 1988 and 1989, barriers to entry for new firms in any country were enormous. Minimum scale for a state-of-the-art facility was approaching a half billion dollars; product life cycles had become shorter, leaving less time for late entrants to recoup investments; and with the significant experience advantage of the Japanese, new entrants would have to fear retaliation. Nonetheless, the Japanese share of the DRAM market declined from about 80% to about 70% between 1986 and 1989, mainly as the result of a surge in share by the Koreans. (Figure 3) Aided by government subsidies and an explicit government commitment to supporting a Korean semiconductor industry, the Korean companies were not deterred by high barriers to entry in the memory market or by the credible threat of a pre-emptive price war by the Japanese companies.[80]

The contrast between the situation facing the Korean companies and the situation facing many American companies which considered re-entering memory production after 1986--either individually or collectively as part of the abortive US Memories initiative--is revealing. The American merchant firms which exited DRAM production in 1985-86 did so believing that the Japanese government was committed to maintaining the Japanese industry and that the Japanese companies, with government help and their own deep pockets, would be able to outlast them in a disastrous price war. Certainly, the methods used by MITI to enforce the trade agreement in ways which benefitted even the weakest Japanese producers only strengthened this belief. Both the Japanese government and the Japanese companies were capable of making a credible commitment to deter the re-entry of most American merchant companies, especially those specializing in memory products where the Japanese threat was the strongest. Not surprisingly, the only credible challenge to continued Japanese dominance in this market segment was mounted by the Korean companies which, like their Japanese competitors, are strengthened by their government's commitment to a domestic semiconductor industry.

The long-term significance of the Korean challenge to competitive dynamics in the memory market should not be overlooked. Although the Japanese continue to dominate the markets for 4M and 16M DRAMS, the frontier-technology products, Samsung, the largest Korean producer, moved into the 1M market in 1990. Largely as a result of this move, the East Asian producers maintained their share of the global semiconductor market in that year, even as the

---

[80]For a complete discussion of South Korean promotional and protectionist policies in the semiconductor industry, see Thomas Howell, et. al., The Microelectronics Race, pp. 148-164. The decline in the Japanese share of the DRAM market reflects almost entirely a rise in the share of the Korean and Taiwanese suppliers.

Japanese share declined for the first time since 1982--from 52.1% in 1989 to 49.5% in 1990.[81] The decline in the Japanese share was primarily the result of two factors--rapid growth in the microprocessor segment in which American firms continue to dominate and a sharp decline in the prices and revenues in the memory segment in which Japanese firms continue to dominate. The collapse of prices in the DRAM market, in turn, was partly the result of efforts by the Japanese companies to respond to the Korean challenge at the low end of the DRAM market.

IV.4. Trade Patterns

So far trends in the directions and shares of international trade between the US and Japan have not been fundamentally altered by the SCTA. Imports as a percentage of US consumption have continued their somewhat erratic upward trend, increasing from about 50% of US consumption before the agreement to more than 60% in 1990. (Table 9) However, the bulk of imports into the US--on the order of 65% to 70%--still originate from the foreign subsidiaries of US companies. Thanks in part to rising DRAM prices, the share of Japanese imports in total US consumption has more than doubled, rising from about 10% before the agreement to over 21% in 1989. In value terms, after increasing steadily between 1986 and 1989, imports from Japan declined by nearly 15% in 1990, but according to estimates of the Department of Commerce, this represents only a .7% decline in the volume of imports from Japan.[82] Overall semiconductor imports in value terms declined by 1.3% between 1989 and 1990 but were still nearly 82% higher than in 1986, and imports of integrated circuits in 1990 were 130% above their 1986 levels. (Table 1) In 1990, the US trade deficit in semiconductors was about $1.4 billion, compared to a 1986 deficit of about $2.5 billion. The drop in the deficit reflects the fact that the growth in overall US semiconductor exports--which increased by 156% between 1986 and 1990--exceeded the growth in overall US semiconductor imports between 1986 and 1990. Japan, however, has remained a relatively small market for US semiconductor exports, accounting for about 10% in 1989 and 1990.

Imports have continued to account for a small share of Japanese consumption of semiconductors during the course of the agreement. After shrinking to a low of about 6% in 1986, imports as a percentage of Japanese consumption rose to about 10% in 1989 (Table 10). But in 1982, imports were 14% of consumption. Both the value of Japanese exports, and the Japanese trade surplus in semiconductors also continued to increase through 1989, significantly boosted by higher DRAM prices. In 1990, however, both indicators fell, as DRAM prices softened and

[81] 1990 market shares are preliminary and are reported in "Preliminary 1990 Worldwide Semiconductor Market Share Estimates: The Microprocessor," Dataquest Report, 1991.

[82] US Department of Commerce, International Trade Commission, US Industrial Outlook, 1991, Chapter 17 (Washington, DC: US Government Printing Office, 1991), p.4.

microprocessor imports increased. (Table 3) Although Japanese imports of semiconductors from the US increased after 1986 both absolutely and as a share of Japanese consumption, the bulk of sales to the Japanese market by American companies--approximately 75% in 1989--did not originate from US locations. (Table 11) The lion's share of US sales in Japan--approximately 60%--come from the three American industry leaders--Motorola, Intel, and TI. Furthermore, Motorola and Intel gained disproportionately during the first two years of the agreement, enjoying a 260% increase in their sales in Japan, compared to a doubling of the overall sales of American companies in Japan. Undoubtedly, a good portion of the incremental Japanese sales of these two companies came from their offshore locations--Intel's and Motorola's assembly operations in Southeast Asia and the Philippines and Motorola's Japanese subsidiary.

V. The Evolution of International Trade in Semiconductors

A logical extension of our argument is that the future of international trade in semiconductors will be a function of three key variables: oligopolistic competition within particular market segments, past and future direct investment decisions by firms, and the degree of intervention by governments around the world. While other factors such as factor costs, domestic competition, and the size of local markets will remain important, they will not be the critical drivers of international trade.

Oligopolistic competition has become especially important because the industry has fragmented into distinct segments and has become highly concentrated within some of them. Of the three segments we have discussed (EPROMs, DRAMs, and microprocessors), firms have realized significant market power in microprocessors and to a lesser extent in DRAMs. In microprocessors, the consequence of market power is that patterns of trade have become virtually determined by individual firm decisions--past and present. During the 1970s, when microprocessors were in their infancy and made largely by US firms, the market was highly competitive: many firms competed actively to win designs. Even through the early 1980s, competition was intense for the microprocessor market because customers required manufacturers to license multiple sources. In the latter half of the 1980s, however, leading microprocessors became sole-sourced products that had significant switching costs for users. As long as a manufacturer had a proprietary design, customers became locked in because software vendors wrote most of their programs explicitly for a particular chip. By 1990, two firms dominated the microprocessor market: Intel with 53.2% share of the world market and Motorola with a 13.3% share. (Table 12) In high performance microprocessors, concentration is even greater. Since over $30 billion worth of software had been written exclusively for Intel's chip by 1990, it has a particularly strong position. The consequence for international trade in microprocessors is that

Intel can build its microprocessors at geographically dispersed plants which fit its organizational priorities and strategy, with limited regard to traditional country-based advantages.[83]

On the other hand, the microprocessor segment, in which American companies currently dominate, could become much more contestable over time for a variety of reasons. First, the legal system in the US has made it difficult for leading firms to hold their dominant positions. Court rulings against Intel's ability to copyright its microcode and trademark its products (the 80386) make it easier for domestic and foreign firms to produce clones. Second, Unix and other new software operating systems such as Microsoft's proposed OS/2 3.0, will hypothetically be hardware independent--i.e., an NEC microprocessor could run programs that today only run on Intel's product. And third, new high performance technologies, such as RISC (reduced instruction set computing) have been developed in the US but licensed widely to companies such as Fujitsu and Siemens. Should these new RISC processors become a standard, radically new trade patterns would emerge in the late 1990s. And finally, the Japanese companies have already shifted the focus of their competition to design-intensive circuits which until now have been the stronghold of American merchants.

Competitive dynamics in DRAMs also reflect the oligopolistic features of the DRAM market. In the 1990s, however, it will become harder to treat this market as a unified one for three reasons. First, the high and low end of this market are likely to become more distinct, especially with the expansion of Korean and Taiwanese manufacturers. Second, with lower switching costs in DRAMs compared to microprocessors, the market tends to be competitive in older technology, lower density chips. When 4M DRAMs are on the frontier, 1M and 256K become increasingly commodity-like; when 16M DRAMs are the frontier, 4M and 1M become commodities with less concentration, etc. In competitive DRAM segments, costs and prices will continue to play a role in determining these trade flows.

Even in these segments, however, it is hard to imagine that the Japanese will cede their domestic market to lower-cost foreign producers. Because of the structure and behavior of the Japanese producers, the Japanese market is not likely to be nearly as competitive as the American or European market, even in low-end products. Therefore, foreign penetration in Japan even in

[83]Intel's assembly plant in Malaysia was built in 1971, when access to Malaysia's low labor costs was critical for assembling Intel's DRAMs. By 1990, chips could be assembled at comparable manufacturing cost with lower logistics costs in Arizona. Similarly, Intel's facilities in Israel started with a design center that emerged partly because of a surplus of engineers in Israel, and partly because a dynamic Israeli-born Intel manager wanted to return home in the mid-1970s. When Intel became a sole source for its microprocessors, it also wanted to offer customers some assurances about risk diversification in case US plants went down. Therefore, it started producing microprocessors in Israel in the 1980s. Finally, the Ireland plant was motivated exclusively by fears over fortress Europe with the coming of 1992 and government tax incentives provided by the Irish government. If history were unimportant and government protectionism were not an issue, Intel would not be shipping microprocessors from Israel, Ireland, or Malaysia.

these products is likely to remain limited, although import penetration may increase sharply as the Japanese move some of their labor-intensive processes to lower-cost locations in East Asia.

Third, competition in DRAMs will continue to be affected by government intervention. Korea and Taiwan have adopted strategies similar to that of Japan. They hope to dislodge the first-mover advantages of Japanese DRAM producers through infant-industry policies of promotion and protection. They have also been helped by the yen exchange rate and encouraged by the rents earned by Japanese producers in 1988 and 1989.[84] Like most cartels, the Japanese DRAM cartel created an attractive market to enter. The capital barriers to entry in DRAMs are high, but the deterrent effects of such barriers depends in part on government policy. The strategies of the East Asian NICs have put pressure on the Japanese to move more quickly to the next generation of memory products or to move into the logic segments where American producers are strong.

By far, the biggest influence on future trade in DRAMs is likely to be the explosion in Japanese foreign investment, encouraged by ongoing trade friction and fueled by the bubble profits of the Japanese companies. One of the greatest fears of Japanese producers is that markets will be closed for their products in Europe and the US. The SCTA as well as changes in the dumping and domestic content laws of the EC have stimulated enormous growth in Japanese foreign investment (Table 13), especially in the US and Europe. Prior to 1990, Japanese firms had limited foreign investment: many firms had assembly plants in Southeast Asia for very low end products, but only four firms had fabrication plants outside of Japan, with five factories in the US, and none in Europe. By 1990, however, virtually every Japanese firm had announced plans for new facilities: 11 (10 of which were memory) were slated for the US, and 10 (8 of which were memory) were proposed for Europe.

In interviews with Japanese firms, their managers argued that "in terms of costs, management of engineers, and the control of production, it was better to produce in Japan."[85] Nonetheless, these firms have decided to invest abroad. The rationale most frequently cited for this decision is trade friction, but there are also other familiar rationales such as 'being close to the customer', access to new engineering talent and technology, and access to foreign capital. Moreover, the pattern of investment by firms confirms Knickerbocker's hypothesis that in oligopolistic industries, smaller companies often follow the industry leader overseas.[86] In

---

[84]Many Japanese critics of the trade agreement argue that the Korean producers were its greatest beneficiaries, followed by the Japanese companies who plowed their bubble profits into further expansion and research and development.

[85]Interviews with Japanese firms, December 1989.

[86]F.T. Knickerbocker, Oligopolistic Reaction and Multinational Enterprise (Cambridge, MA: Harvard Business School, 1973).

semiconductors, the largest Japanese producer--NEC--pioneered investment in the US and was the first to invest in Europe. The other large semiconductor firms--Hitachi, Mitsubishi, Toshiba and Fujitsu--lagged two to three years behind NEC, while smaller firms either eschewed foreign fabrication investment (e.g., Sony) or postponed making investments as long as possible (e.g., NMB).[87]

If relatively few Japanese firms continue to dominate the high end of the DRAM market, as seems likely, the pattern of trade in DRAMs should look very different at the end of the 1990s than it looks today. Export growth from Japan will decline, replaced with local Japanese production in the US and Europe. On the other hand, if the market becomes more competitive--if Korea and Taiwan successfully challenge NEC, Toshiba, and the other large Japanese firms--then trade in DRAMs will follow a more conventional path, as new low-cost producers gain share.[88] For the reasons listed earlier, foreign penetration of the Japanese market is likely to remain limited, although import penetration from Japanese production facilities abroad is likely to increase, especially if the Koreans and Taiwanese become a more significant threat.

The EPROM market is the least concentrated, most competitive market, yet production in EPROMs in the 1990s will not necessarily migrate to the lowest cost locations. The strategic considerations of selected US and European firms will continue to influence EPROM trade. Most semiconductor firms operate on the philosophy that they must have a large volume technology driver to improve their manufacturing yields.[89] Since most US and European firms exited from DRAMs (the technology driver of the Japanese firms), EPROMs remain one of their best hopes. For these firms, the barriers to exit are enormous: they fear that if they leave the EPROM business, they may ultimately lose competitiveness in their higher margin products. Therefore, many firms are willing to treat EPROMs as a loss leader, producing a pattern of trade that will largely be a function of the staying power of individual firms. In other words, US and European firms may continue to be significant players in EPROMs, even though they have no locational advantages.[90]

---

[87] Interviews with Japanese firms, December 1989.

[88] According to one American manager, some Japanese firms were trying hard to create a new cartel in 1991 to undermine Korea's and Taiwan's ability to use their factor cost advantage to change the pattern of trade. Some Japanese firms were allegedly using their strong position in critical segments of the semiconductor equipment business as a source of leverage to get the Koreans, in particular, to be less aggressive on DRAM pricing.

[89] An ideal technology driver has to fulfill three requirements: easy conversion of manufacturing equipment and producer technologies to new devices; state-of-the-art density circuits that stress the limits of current technology--consequently the design of a technology driver should be simple, repetitive, and easily testable; and large scale of production. Historical experience idicates that DRAMs are superior to alternative technology drivers like EPROMs and SRAMs which cannot be profitably produced in large enough quantities to reap economies of scale and learning. Ernst and O'Connor, "Competing in the Electronics Industry--The Experience of Newly Industrializing Countries," p. 89.

[90] There are two other possible scenarios for EPROMs. First, the Japanese (or the Korean and Taiwanese) firms

Moreover, the location of production and/or assembly for EPROMs will not necessarily be a company's home base. Firm-specific logic continues to guide locational choices. Although American firms closed some inefficient overseas plants in the 1980s, companies such as National Semiconductor, Texas Instruments, Intel, and AMD continue to operate from developing countries and European locations that were set up in the early 1970s. National Semiconductor's experience is fairly typical and offers insight into the future of American semiconductor trade. National's plants were set up initially to economize on labor costs and take advantage of government incentives.[91] As the industry changed, National sold off or closed some inefficient facilities, but expanded only in old locations. Even though Japan might have been "the best" new location, for instance, National preferred to maintain its existing network. In essence, firms like National followed an internal organizational logic in deciding upon location decisions rather than treating previous foreign investments purely as sunk costs. From the firm's perspective, it may be cheaper in terms of human and other resources to continue from an existing site than to start, de novo, at a new location. As a consequence, international trade in strategic products like EPROMs is likely to remain heavily affected by past investment decisions. Exports will not follow a country-based logic; instead, products will be exported according to the global configuration of existing firms (for example, fabricating in the Silicon Valley, Israel or Scotland, assembling in Southeast Asia, and shipping to final markets around the world).

VI. Conclusions

Trade patterns in the semiconductor industry have never been explainable solely on the basis of traditional country variables. From the industry's inception, government policies first in the United States, then in Japan and Europe, and now in the newly industrializing countries, have manipulated factor costs, demand, and competitive rivalry. By the mid-1980s, government policies went even further to manage trade flows and pricing directly.

The effects of heavy government intervention varied by the type of policy employed and

---

may yet dislodge the incumbents by virtue of their dominant position in DRAMs. The DRAM market is five times larger than the EPROM market; therefore, leaders in DRAMs have much higher volumes than the largest EPROM manufacturers and potentially can drive their manufacturing processes down the learning curve at much faster rates. In the absence of government intervention, such as the SCTA which has inhibited aggressive Japanese behavior in EPROMs, Japanese firms might build a huge cost advantage from their DRAM manufacturing operations to drive even the most committed non-DRAM manufacturer out of the EPROM market. A second scenario is that technological changes will lead the incumbent firms to exit. Manufacturers of certain logic products have found SRAMs to be better technology drivers than EPROMs. If EPROMs are no longer critical for higher margin businesses, there are fewer incentives for firms to retain their market position. Interview with industry executive, February 1991.

[91] Interview with National Semiconductor executives, 1989.

by how well it matched the industry's condition at the time it was employed. During the nascent phases of semiconductor development, US military procurement and active anti-trust policy had significant and positive effects on American producers. These policies provided secure demand at a time when the technological risks might have been prohibitive for most private firms, and stimulated innovative competition, which pushed the industry to develop new, exciting products. Although the transistor emerged from an industry giant--AT&T--the ICs, DRAMs, EPROMs and microprocessors were American inventions that emerged from entrepreneurial firms like TI, Fairchild and Intel.

Japanese government policies were very different, but also appropriate for their time. When the industry was a little more mature, Japanese protection and promotion policies also sought to reduce the risk in semiconductor production, but they did so through *less competition*, both at home and from abroad. In almost classic John Stuart Mills' fashion, Japan demonstrated that under the right conditions infant-industry protection works.

One consequence of different Japanese and US government policies was the creation of distinctive industry structures. While both industries were fairly concentrated, US semiconductor companies were relatively small, specialized firms that made chips as their only business or as their biggest business. Japanese firms, by contrast, were all part of large electronics conglomerates.[92]

Government intervention in any large domestic market would inevitably have an effect on international trade in semiconductors because of the industry's unusual economics. With very large scale economies and steep learning curves at the plant level, and extraordinarily high R&D requirements at the corporate level, few firms in any country could survive and prosper without selling overseas. Moreover, these features of the industry gave first movers significant competitive advantages--leaders could often set standards, forcing followers to play catch-up; and leaders could move down the learning curve, raising barriers for late arrivals. Since such early moves often lasted through the current generation of products, it behooved firms to enter international markets as aggressively as they entered domestic markets. In a relatively open market, the first mover advantages initially accumulated by US firms should have preempted Japanese competition; but the Japanese government prevented this outcome. Similarly, if the market had been free of government intervention in the 1980s, Japanese-first-mover advantages should have blocked other new entrants, such as Korea and Taiwan. Repeatedly, government intervention foiled competitive advantages won by other nations. In essence, the scale and learning economies of semiconductors created a potentially significant role for government

[92]This point has been emphasized by Charles Ferguson in several pieces. See, for example, "From the People Who Brought you Voodoo Economics," Harvard Business Review 3 (May-June 1988): 55-62.

intervention, just as the strategic trade policy literature has long suggested. The governments of the US in the 1960s, Japan and Europe in the 1970s and 1980s, and Korea in the 1980s and 1990s effectively capitalized on that opportunity.

The semiconductor experience also teaches us about the powerful influence of history on firm production and export decisions. As long as key segments of the semiconductor market are not challenged by new, low-cost producers, incumbent firms have the freedom to manufacture and assemble products in locations which do not identically match country advantages. If the semiconductor industry had started in this decade, with Japanese and American firms holding the same positions they held in 1990, the structure of world exports would be very different. The volume of products shipped from Southeast Asia would be substantially reduced; direct US exports would be much greater; and facilities in Ireland, Scotland, Israel, and various locations on the European continent might not even exist.

Individual corporate histories can have an abnormally large impact on semiconductor trade flows for at least two reasons: first, the increasing segmentation of the market and the growing concentration within individual segments; and second, the "strategic" nature of certain high-volume, technology-driver products like EPROMs and DRAMs. In the first case, when segments are concentrated and not easily entered, small (and under some conditions, even large) differentials in costs do not matter. Firms will produce in historical locations as long as they can price to recover the higher costs and they have mechanisms other than price (e.g., proprietary technology) to deter entry. In the second case, firms are willing to sacrifice profits on strategic product lines to retain their market position in other product lines. Moreover, the economies of scope between a commodity product and a high margin product can be so great that profits earned on the high value IC more than compensate for the losses in the commodity business. Even when new lower cost locations emerge, incumbent firms may continue to produce their strategic lines in existing locations because the total cost of relocation exceeds the marginal cost of staying put.[93]

Finally, the semiconductor experience demonstrates the difficulties involved in predicting the effects of trade policy on trade flows when the industry in question is oligopolistic and when many of the big players have extensive global operations. The effects of the SCTA on trade patterns depended on the production, investment, and trade decisions of a relatively small number of Japanese and American companies. Because of differences in their structure and strategies, these companies reacted differently. In DRAMs, for example, the Japanese companies, with the help of MITI, were able to form a temporary collusive arrangement that worked to their benefit.

[93]Of course, unless the economies of scope are very great, incumbents in competitive markets will eventually have to move production in commodity products to lower cost locations. Otherwise, the losses in a commodity product like EPROMs might exceed the gains in the firm's other logic products. However, according to our reasoning, these lags may be very long.

As a result, the SCTA initially reduced DRAM competition. In contrast, the SCTA increased competition in the EPROM market, as American and European companies vied for the share made available by the retreating Japanese producers.

The choices of individual firms about production locations also influenced how the SCTA affected trade flows. Had TI and Motorola chosen to respond to improved incentives for DRAM production by further expansion of their US facilities and less expansion of their facilities in Japan, more of the increase in the share of American companies in the Japanese market would have come from an increase in US exports. Instead, most of the increase in American sales to the Japanese market came from the production of American companies in Japan and third-country locations. (Table 11) Although the SCTA seems to have been a qualified success in improving access for American companies to the Japanese market, it was less successful than it might have been at increasing direct exports of semiconductors to Japan from US locations. Since American firms produced some of their products in Japan and assembled other products in Southeast Asia, the US-Japanese trade balance in semiconductors was not materially improved.

In fact, the SCTA had remarkably little effect on trade patterns in the US and Japan. Imports in the US continued to grow, both in value terms and as a share of US consumption, through 1989. The drop in US imports in 1990 was the consequence of lower DRAM prices--in real terms, imports from Japan were virtually unchanged. Imports from Japan continued to increase as a share of US consumption through the period, although sales from the foreign subsidiaries of American companies continued to account for the bulk of US imports. On the Japanese side, there was some increase in the share of imports in Japanese consumption, especially in 1988-90, reversing a declining trend between 1982 and 1986, but the overall share remained below levels realized in the early 1980s. Japan's exports and trade surplus in semiconductors continued to grow through 1989, but declined in 1990 mainly as a result of lower DRAM prices.

Judged by the trade results alone, the SCTA appears to have been relatively ineffective. But judged by its impact on prices, market shares, and competitive dynamics in key industry segments, the SCTA appears to have had some important consequences. The evidence indicates that the agreement was a qualified success relative to some of its objectives--the US share of the global DRAM market stabilized; the precipitous decline in the US share of the global EPROM market was reversed; and the share of US companies in the Japanese market increased.

Nor did the trade agreement reduce competition across all market segments, as most critics of managed trade arrangements predicted. Competition in the EPROM market actually increased as a result of the agreement. Competition in the DRAM market decreased initially, as the agreement allowed the Japanese producers to consolidate their market power. But over time, the DRAM market too became more competitive as a result of several factors including: an increase in production by American companies like TI and Motorola; the growing strength of

South Korean suppliers, promoted by their government and attracted by the hefty profits earned by the Japanese; and the expansion of production capacity in Europe, encouraged in part by European policies to develop its own regional supply base in semiconductors in the wake of supply shortages and higher prices in 1986-88.[94]

Even if we accept the view that the trade agreement was a qualified success relative to its objectives, we must ask whose interests were served. Certainly, some American companies appear to have benefitted--especially TI, which remained a significant player in the DRAM market; and Motorola, which re-entered that market. TI, Motorola, and other American companies also enjoyed somewhat greater opportunities to compete and sell in the Japanese market, the largest and fastest growing market for semiconductors in the world. But Koreans and Japanese may be the long run winners.

The effects of the agreement on the users of semiconductors are harder to evaluate and present a more mixed picture. Without question, the agreement played some role in precipitating the sharp spike in DRAM prices between mid-1987 and mid-1989, and this hurt major users, especially US computer companies, which relied on Japanese suppliers for their memory inputs. And even though EPROM prices did not spike upwards, the agreement may well have kept them from falling sharply in response to a price war initiated by the Japanese. Such a price war was underway in 1986 but was effectively ruled out by the anti-dumping provisions of the agreement.

Over the longer run, however, the agreement seems to have generated greater competition in EPROMs and greater competition in DRAMS as well. And if the improved access of foreign producers to the Japanese marketplace ultimately weakens the market power of the Japanese keiretsu firms, as the trade agreement intends, then users of semiconductors may benefit further from greater competition in the future.

Even if we limit our assessment of the agreement's benefits to the producer side of the equation, an important question remains: did the US gain as a result of the benefits realized by US companies, most of which had at least some of their production operations abroad. On the one hand, the SCTA allowed American companies to enhance many of their high-value-added activities, especially in R&D and fabrication, and the lion's share of these activities are still located in the US[95] On the other hand, much of the gain in the market share of US companies reflected increased sales from their subsidiary operations. And ironically, in the long run, America as a production site for semiconductors may benefit most from the foreign direct investment of Japanese firms trying to protect their share of the American market from future trade barriers.

As these reflections suggest, when global American companies are the beneficiaries of

[94]For an insightful analysis of the European strategy, see Flamm, "Semiconductors."

[95]Laura D' Andrea Tyson, "They are Not Us: Why American Ownership Still Matters," The American Prospect (Winter 1991): 37-49.

American trade initiatives, American trade negotiators must ask the question "Who Is Us?"[96] This is a question for future research. In the meantime, the evidence presented in this paper indicates that contrary to widely held beliefs, the semiconductor trade agreement has been at least a qualified success relative to its objectives. In a world of heavily manipulated trade, managed trade has not proven to be a dismissable second-best alternative.

Looking to the future, the massive flow of Japanese foreign direct investment motivated by the threat of trade protection in the US and Europe is likely to be the single most important factor determining shifting trade patterns in the semiconductor industry in the 1990s. Nations will continue to promote domestic semiconductor producers and continue to manipulate or manage trade flows, but patterns of global competition and trade will increasingly be affected by the globalization strategies of the all of the major producers, regardless of their nationality or home-country base.

---

[96]Robert Reich, "Who Is Us?" Harvard Business Review (Jan.-Feb. 1990): 53-64, and see Ken Froot and David Yoffie," Strategic Trade Policy in a Tripolar World." Working Paper 91-030, Harvard Business School 1991.

Table 1

Total U.S. Semiconductor Trade

Exports					Imports				
	Total	Integrated Circuits	Transistors, Diodes & Rectifiers	Other*		Total	Integrated Circuits	Transistors, Diodes & Rectifiers	Other*
	Millions of dollars					*Millions of dollars*			
1966	130.4	8.9	91	30.5	1966	44.6		28.7	15.9
1967	152.4	26.5	81.4	44.1	1967	46.5		26.7	19.8
1968	204.5	36.2	89.5	78.8	1968	76.6		44.7	31.9
1969	345.7	72.4	138.6	134.7	1969	111.2		59	52.2
1970	416.9	99.8	146.2	170.9	1970	167.7	69.4	59.8	38.5
1971	370.5	91.2	99.9	179.4	1971	187	94.2	60.4	32.4
1972	469.6	103.5	126	240.1	1972	328.8	180.5	100.1	48.2
1973	848.6	217.7	195.8	435.1	1973	610.5	365.3	160.6	84.6
1974	1247.5	313.5	215.6	718.4	1974	953.5	606.3	235.9	111.3
1975	1037	262.1	111.6	663.3	1975	802	581.5	138.5	82
1976	1385.9	320.4	120.3	945.2	1976	1098	813.7	153.1	131.2
1977	1490.5	348.1	70.6	1071.8	1977	1403.2	1025	173.5	204.7
1978	1521.4	471.9	85.4	964.1	1978	1827.4	1405.2	179.1	243.1
1979	2075.1	650.1	90.9	1334.1	1979	2587.7	2035.4	195	357.3
1980	2782.3	833.5	95.2	1853.6	1980	3395.6	2780.4	212.2	403
1981	2832.7	768.4	87.3	1977	1981	3645.5	2982.1	264	399.4
1982	3058.9	836.3	81.8	2140.8	1982	4397	3501	263.9	632.1
1983	3673.5	1025.7	97.9	2549.9	1983	5330.1	4150.2	257.4	922.5
1984	4651.5	1391.3	118.8	3141.4	1984	8284.2	6135.8	345.9	1802.5
1985	3693.1	1140.6	123.1	2429.4	1985	6369.7	4423.9	259.4	1686.4
1986	4185.4	1148.1	138.8	2898.5	1986	6685.7	4539	303.7	1843
1987	6229	1622.8	131.4	4474.9	1987	8561.9	6038.1	336.8	2187
1988	8035.4	2588.5	168.4	5278.5	1988	12089.8	8767.6	425.2	2896.9
1989	9530.6				1989	12301.6			
1990	10709.6				1990	12143.5			

*Other Semiconductor Devices

Sources:

1966-72: US Department of Commerce Publications #ES-2:15

1973-76: US Department of Commerce Publications #ES-2:17

1977-82: US Department of Commerce Publications #ES-2:19

1983-86: US Department of Commerce Publications #ES-2:20

1987-88: Complied from US Department of Commerce Publications #FT-246

1989-1990: Complied from Official US Department of Commerce Statistics

(Breakdowns for 1989-1990 were not available due to a change in classification from SIC to a Harmonized System)

Table 2

MITI-Sponsored Joint Research and Development Projects in Microelectronics*

Project	MITI VLSI	Opto Electronics	Super Computer	New Function Elements	SORTEC**	Optoelectronic Devices	Fifth Generation Computer
Time Frame	1975-79	1979-86	1981-89	1981-90	1986-96	1986-96	1981-91
Technological Focus	VLSI Manufacturing	Optical Semiconductors	High Speed Devices	VLSI Device & Process	Synchotron Lithography	Optical Semiconductors	VLSI logic
Govt. Funding (Millions of Dollars)	112	80	135	140	62	42	NA
Participants	NEC Hitachi Fujitsu Toshiba Mitsubishi	NEC Hitachi Fujitsu Toshiba Mitsubishi Oki Sumitomo	NEC Hitachi Fujitsu Toshiba Mitsubishi Oki Sharp	NEC Hitachi Fujitsu Toshiba Mitsubishi Oki Sharp Sanyo Sumitomo Matsushita	NEC Hitachi Fujitsu Toshiba Mitsubishi Oki Sharp Sanyo Sumitomo Nippo Sh. Glass Matsushita Nippon Kogaku	NEC Hitachi Fujitsu Toshiba Mitsubishi Oki Sharp Sanyo Sumitomo Nippon Sh. Glass Fujikura	NEC Hitachi Fujitsu Toshiba Mitsubishi Oki Sharp

Source: Nihon Keizai (May 6 and May 26, 1986); U.S. Embassy, Tokyo   **Yen:Dollar Conversion Average for the Period*   ***Funded through Japan Key Technology Center*

Table 3

Total Japanese Semiconductor Trade

Exports			Imports		
Year	Integrated Circuits	Total	Year	Integrated Circuits	Total
Millions of dollars			*Millions of dollars*		
1967	n/a**	16.6	1967	5.0	17.0
1968	n/a**	18.7	1968	12.0	27.5
1969	n/a**	27.1	1969	21.8	47.7
1970	n/a**	27.2	1970	57.4	92.5
1971	n/a**	27.9	1971	69.6	89.8
1972	6.8	42.0	1972	54.2	81.3
1973	9.5	84.3	1973	122.5	181.8
1974	22.9	130.8	1974	154.7	206.3
1975	45.5	140.8	1975	134.9	182.9
1976	76.7	236.0	1976	199.4	280.7
1977	117.9	309.4	1977	207.6	291.7
1978	248.2	480.4	1978	291.4	378.0
1979	494.5	753.8	1979	449.6	556.2
1980	808.8	1087.6	1980	480.3	609.3
1981	904.9	1236.5	1981	517.8	686.7
1982	1144.8	1425.9	1982	511.4	641.2
1983	1784.2	2150.0	1983	642.4	785.9
1984	3271.2	3778.3	1984	935.6	1137.4
1985	2439.7	2920.9	1985	693.8	836.3
1986	3107.4	3797.3	1986	867.7	1026.2
1987	4096.6	5005.4	1987	1125.4	1307.6
1988	6598.3	7915.4	1988	1761.0	2003.1
1989	8313.0	9681.1	1989	2246.9	2547.0
1990	7595.1	9005.4	1990	2589.1	2921.3

*During the 1965-66 period, the Japanese exported only Discrete Semiconductor Devices (DSD); these included germanium transistors, silicon transistors, germanium diodes, silicon diodes, and silicon diodes for silicon rectifiers. (Thus, the data do not include Integrated Circuits for this period.) **In the 1967-1972 period, the Japanese began exporting Integrated Curcuits (ICs), however, the data do not distinguish between ICs and DSD.

Source: Japan Electronics Bureau, JETRO.

Table 4

Worldwide Semiconductor Market Share

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
U.S.	51.4	51.4	49.0	48.4	45.4	41.5	39.0	36.5	35.4	39.7
Japan	35.5	35.3	38.8	39.7	41.7	45.9	48.2	51.0	51.3	48.0
Europe	12.9	12.7	11.3	11.0	11.7	11.2	11.0	9.7	9.7	12.3

Source: Dataquest

Table 5

Average Selling Prices of DRAMs

256K DRAM Prices			1M DRAM Prices		
Dollars per chip			*Dollars per chip*		
1984			1985		
	Q1	31		Q1	150
	Q2	23.5		Q2	125
	Q3	17.5		Q3	110
	Q4	14		Q4	100
1985			1986		
	Q1	9.5		Q1	48
	Q2	5.15		Q2	34
	Q3	3		Q3	45
	Q4	2.25		Q4	25
1986			1987		
	Q1	2.25		Q1	17
	Q2	2.3		Q2	15
	Q3	2.5		Q3	13.5
	Q4	2.2		Q4	15
1987			1988		
	Q1	2.25		Q1	15.2
	Q2	2.3		Q2	16.51
	Q3	2.4		Q3	17.48
	Q4	2.45		Q4	17.28
1988			1989		
	Q1	2.79		Q1	17.42
	Q2	2.97		Q2	16.36
	Q3	3.19		Q3	12.83
	Q4	3.3		Q4	9.46
1989					
	Q1	3.46			
	Q2	3.55			
	Q3	2.61			
	Q4	2.22			

Source: Dataquest

Table 6

DRAM Pricing, 1987-1989

	1987	Q2	Q3	1988	Q2	Q3	Q4	1989	Q2	Q3	Q4
	Dollars Per Chip										
1M-Japan	14.5	14.8	15.5	15.5	15.6	15	15.3	14.9	13.8	13	13
1M-U.S.	17.5	16.5	20.5	22.5	22.5	20.5	19.5	16	16	12.8	12
1M-Europe	15.5	15.7	16	23	19.7	17	17.8	16	16.5	12	11
256K-Japan	2.1	2.3	2.5	2.5	2.7	2.5	3.1	2.8	2.5	2.7	2.9
256K-U.S.	2.4	2.5	2.9	3.2	3.5	3.7	3.9	4	3.9	3	3
256K-Europe	2.5	2.6	3	3.5	4	5	6	5.5	3.8	2.9	2.9

Source: Dataquest, Biweekly Data

Table 7

Average Selling Prices of EPROMs

256K EPROM Prices (Dollars Per Chip)			1M EPROM Prices (Dollars Per Chip)		
1984			**1986**		
	Q1	77.59		Q1	150
	Q2	48.11		Q2	73.13
	Q3	37.17		Q3	59.75
	Q4	29.47		Q4	55.78
1985			**1987**		
	Q1	21.55		Q1	36
	Q2	12.14		Q2	30.4
	Q3	5.67		Q3	27.17
	Q4	4.63		Q4	25.69
1986			**1988**		
	Q1	4.32		Q1	21.55
	Q2	4.71		Q2	20.36
	Q3	4.73		Q3	19.3
	Q4	4.47		Q4	18.54
1987			**1989**		
	Q1	4.47		Q1	17
	Q2	4.59		Q2	14
	Q3	4.71		Q3	11
	Q4	4.73		Q4	8
1988					
	Q1	4.87			
	Q2	4.83			
	Q3	4.86			
	Q4	4.89			
1989					
	Q1	4.4			
	Q2	3.64			
	Q3	3.07			
	Q4	2.07			

Source: Dataquest

Table 8

256K EPROM Pricing 1987-1989

	1987	Q2	Q3	Q4	1988	Q2	Q3	Q4	1989	Q2	Q3	Q4
	Dollars Per Chip											
Japan	2.63	3.09	4.14	4.69	4.69	4.8	4.56	5	4.43	3.61	3.35	3.5
U.S.	3.9	5.4	5	4.55	4.3	4.15	4	3.5	3.15	3.05	2.5	2.4
Europe	3.75	5.1	5.1	4.8	4.7	4.1	4.2	4.1	4.08	2.65	2.2	1.95

Source: Dataquest, Biweekly Data

Table 9

Imports as a Share of U.S. Consumption of Semiconductors

	Total Imports	Imports from Japan
	Percent	
1982	56.8	7.5
1983	49.1	8.1
1984	50.4	12.3
1985	52.7	10.6
1986	47.4	9.8
1987	53.0	11.7
1988	60.5	16.0
1989	62.5	21.1

Source: Dataquest

Table 10

Imports as a Share of Japanese Consumption of Semiconductors

	1982	1983	1984	1985	1986	1987	1988	1989
Imports from U.S.	10%	10%	9%	6%	5%	5%	6%	7%
Imports from non-U.S.	4%	3%	2%	1.50%	1%	1.50%	2%	3%

Source: Ministry of Finance, Dataquest

Table 11

1990 Shares of the World Microprocessor Market

	Rank	Market Share
Intel	1	53.20%
Motorola	2	13.30%
Advanced Micro	3	5.10%
Hitachi	4	3.60%
NEC	5	3.50%
National Semi.	6	2.70%
SGS-Thomson	7	2.30%
Toshiba	8	2.10%

Source: Dataquest

Table 12

U.S. Exports and Sales of U.S. Companies in Japan, 1984-1989

	1984	1985	1986	1987	1988	1989
	Millions of Dollars					
Imports from the U.S.	278	149	169	256	371	543
Sales of U.S. Companies	965	695	948	1255	1956	2147

Source: Constructed by authors from Japan Ministry of Finance data and Dataquest data

Table 13

Percentage of Offshore IC Production *

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994**
							Percent								
Japan	0.0	0.0	0.0	0.0	3.0	4.0	6.0	8.0	10.0	15.0	20.0	22.0	25.0	27.0	28.0
U.S.	50.0	65.0	74.0	71.0	66.0	70.0	67.0	66.0	67.0	65.0	64.0	63.0	62.0	61.0	61.0
Europe	50.0	35.0	25.0	27.0	30.0	25.0	29.0	28.0	26.0	25.0	24.0	21.0	20.0	20.0	19.0
Asia/Pacific	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	5.0	5.0	5.0	6.0

*Production done in company-owned foreign facilities

**Projected

Source: Dataquest

Figure 1: Proportions of U.S. Semiconductors Produced Within the U.S. vs. Abroad

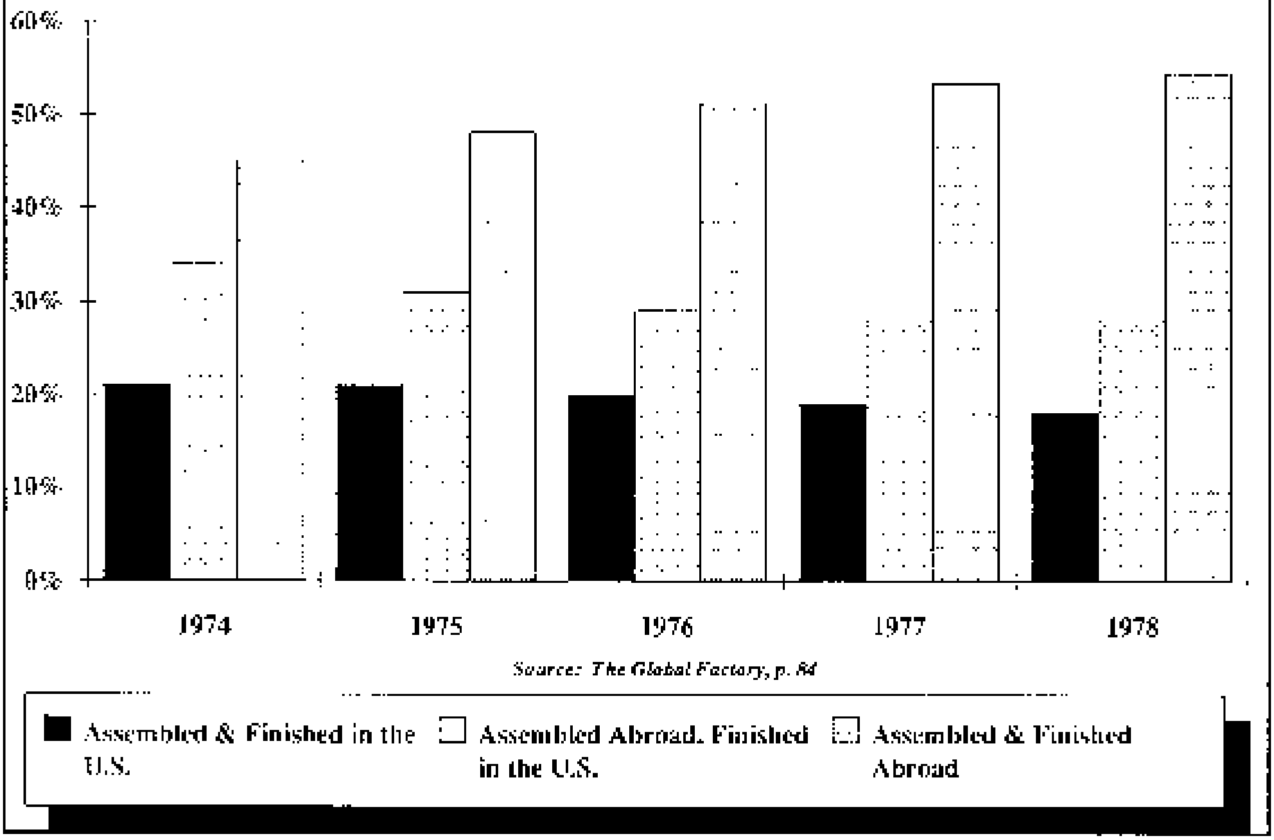
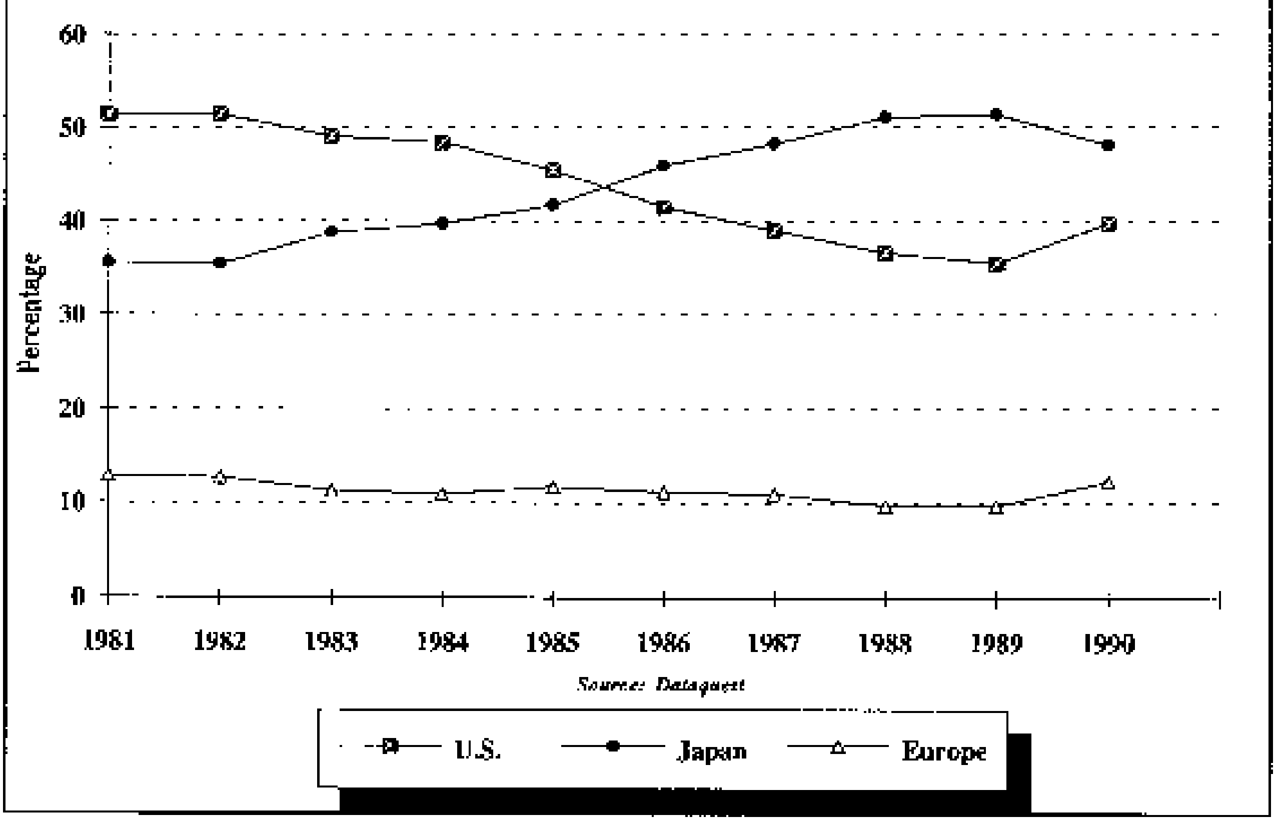


Figure 2: Worldwide Semiconductor Market Share 1981-1990



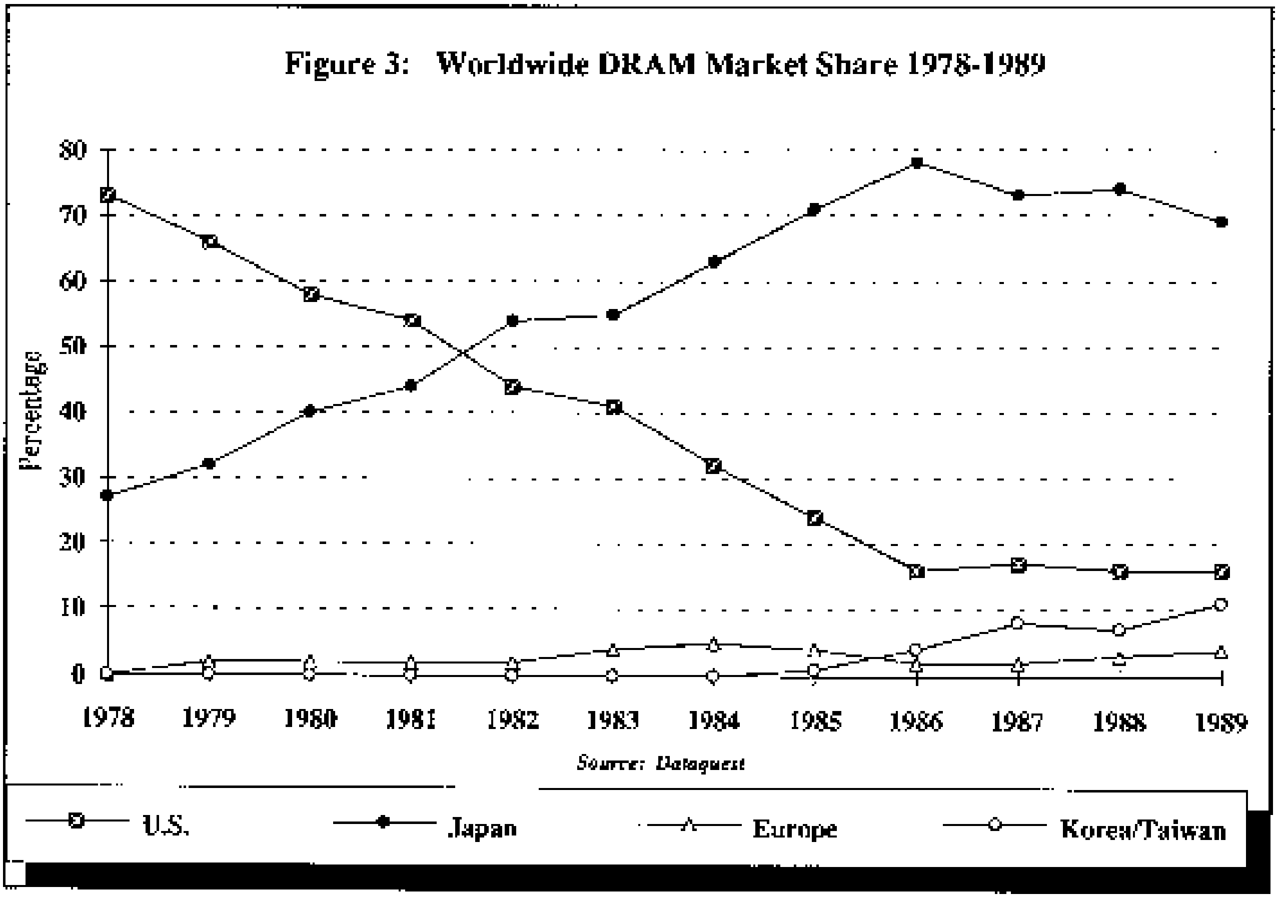


Figure 3: Worldwide DRAM Market Share 1978-1989
Percentage
80
70
60
50
40
30
20
10
0
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
Source: Dataquest
U.S.
Japan
Europe
Korea/Taiwan

Figure 4: Worldwide EPROM Market Share 1978-1989

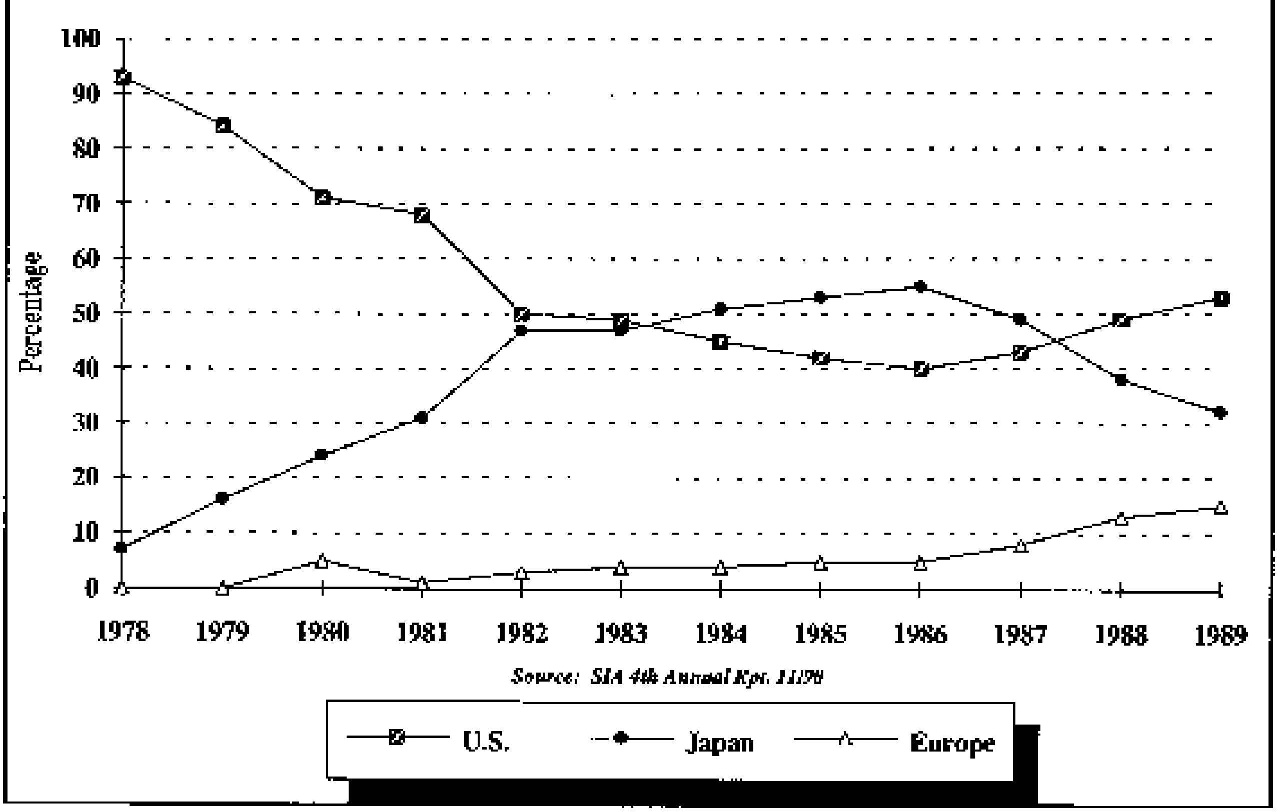


Figure 5: World Semiconductor Consumption

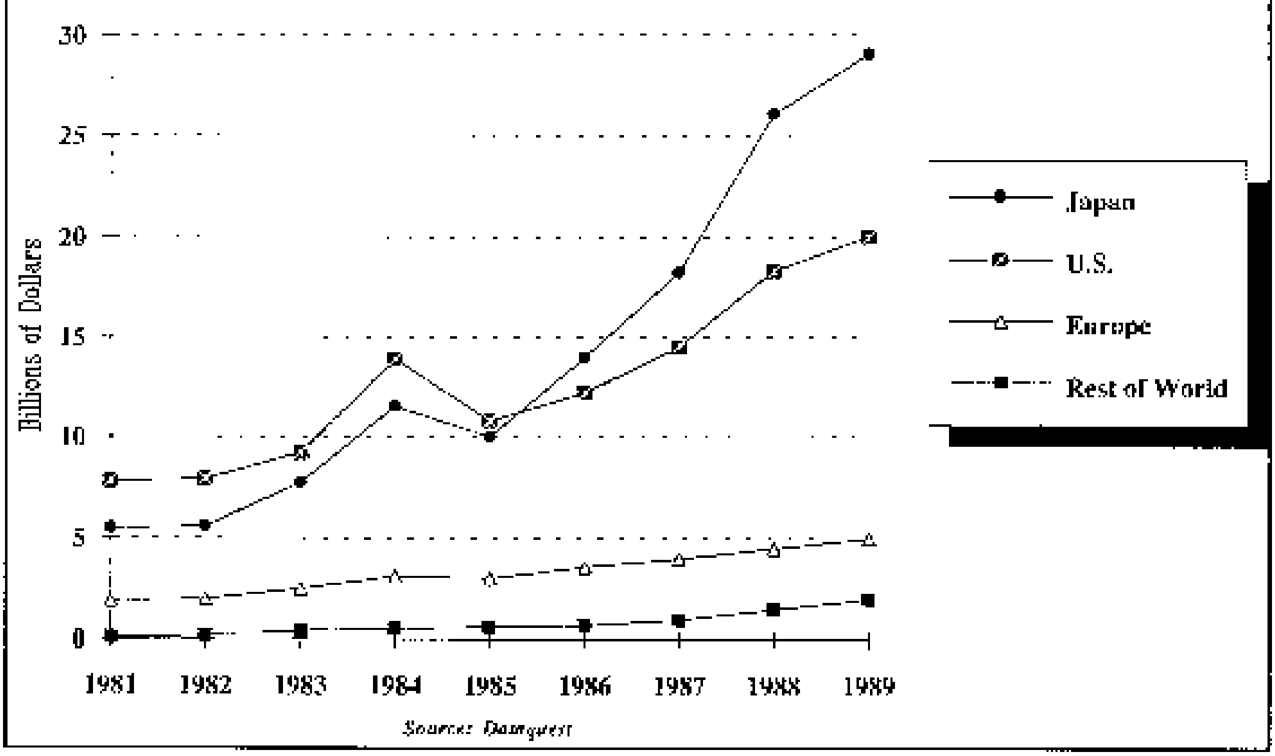
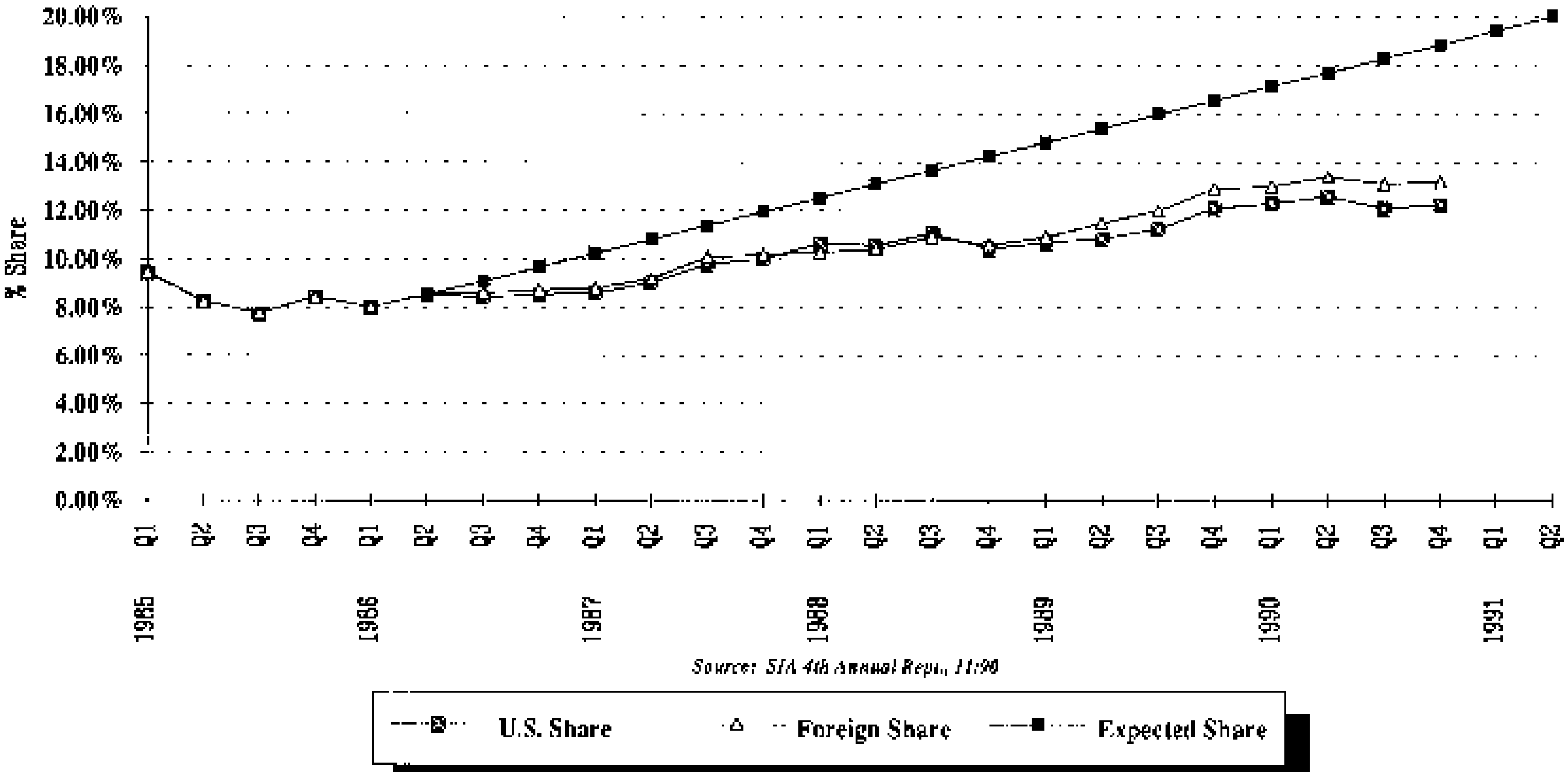


Figure 6: Foreign Semiconductor Market Share in Japan



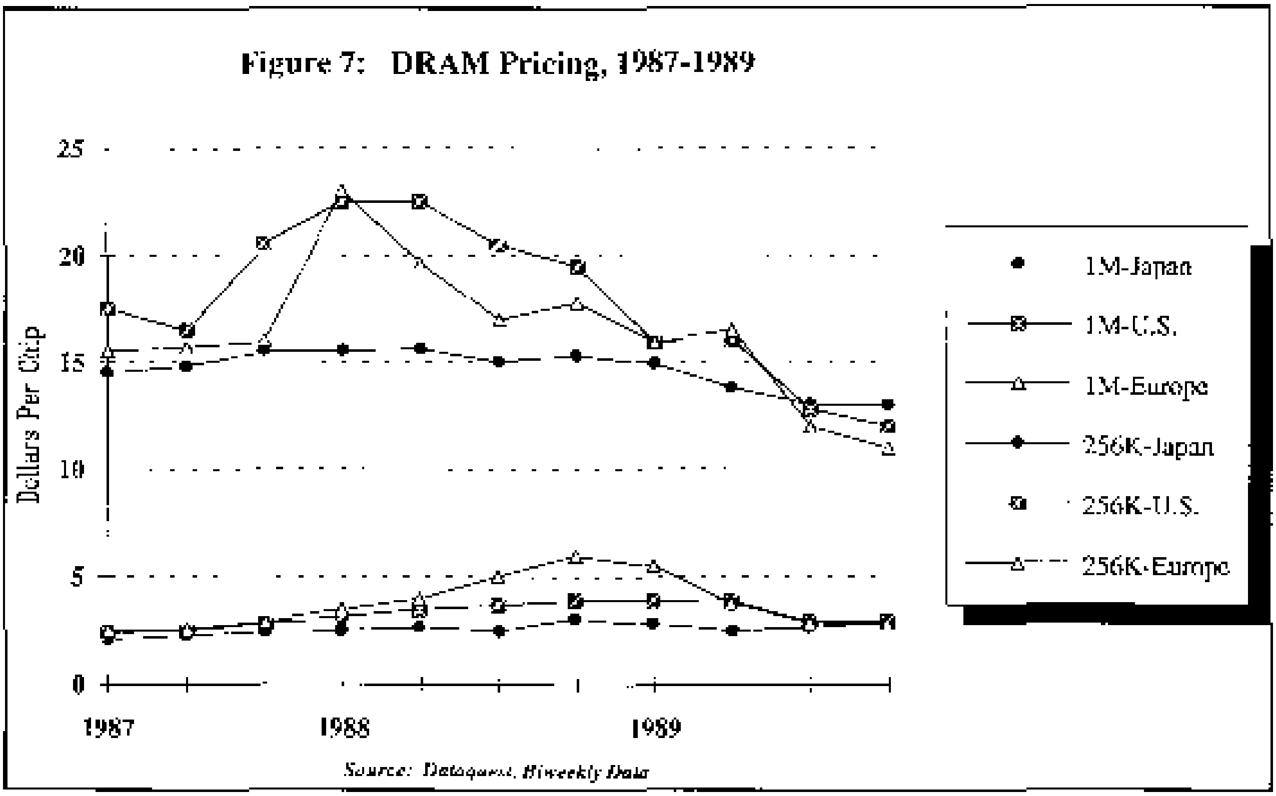
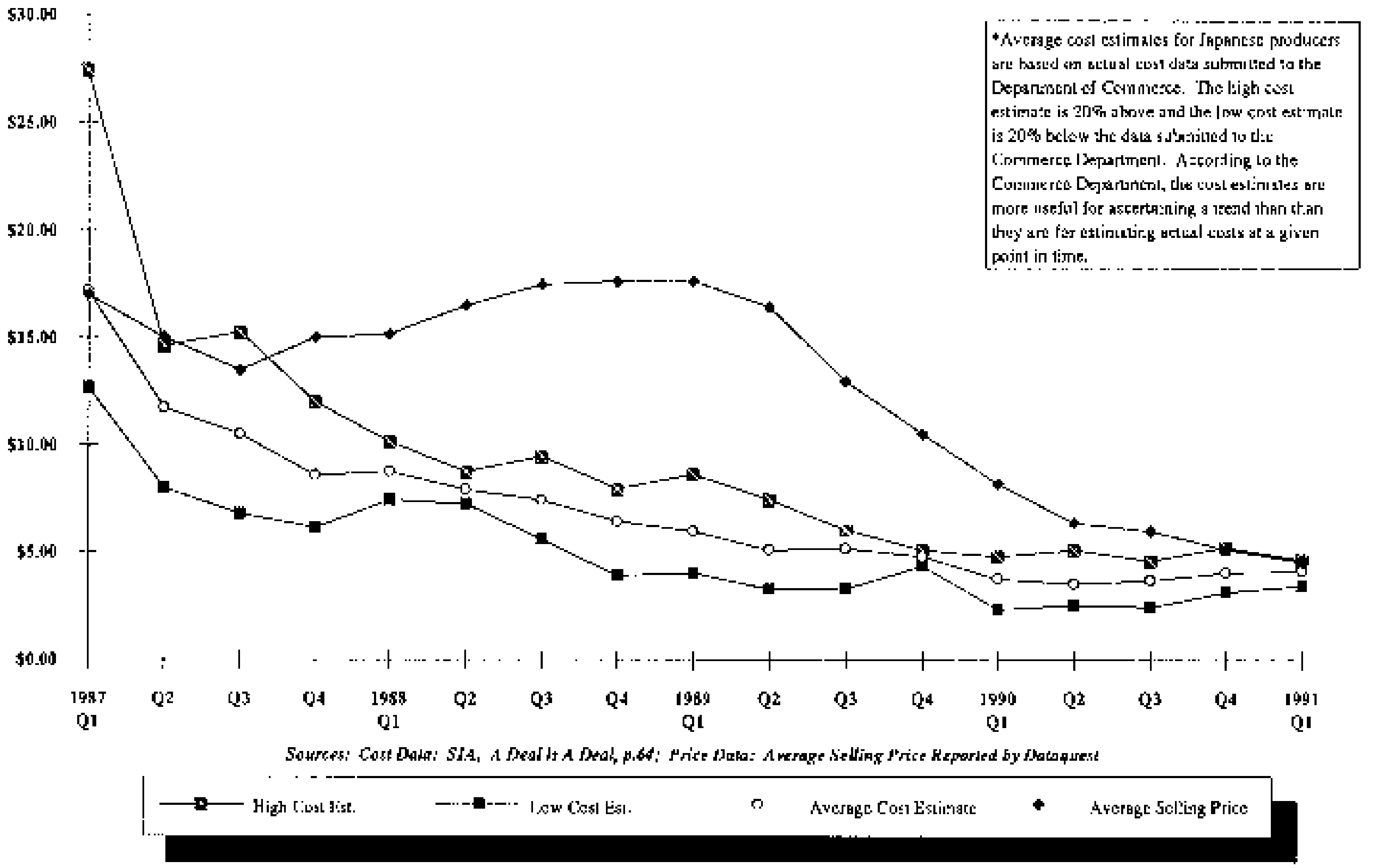


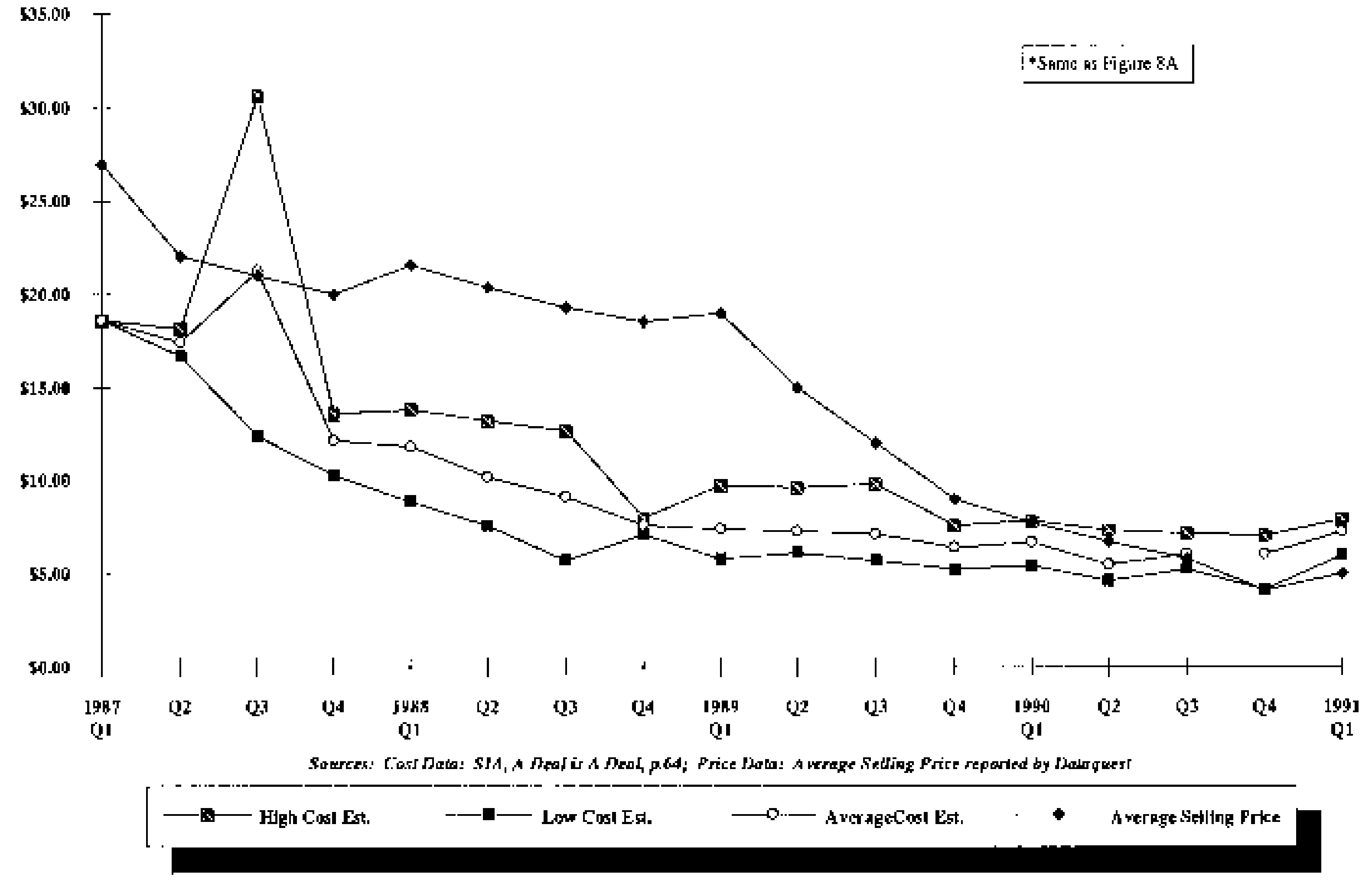
Figure 7: DRAM Pricing, 1987-1989
25
20
15
10
5
0
Dollars Per Chip
1987
1988
1989
1M-Japan
1M-U.S.
1M-Europe
256K-Japan
256K-U.S.
256K-Europe
Source: Dataquest, Biweekly Data

Figure 8A: 1M DRAM Average Cost* and Average Selling Price



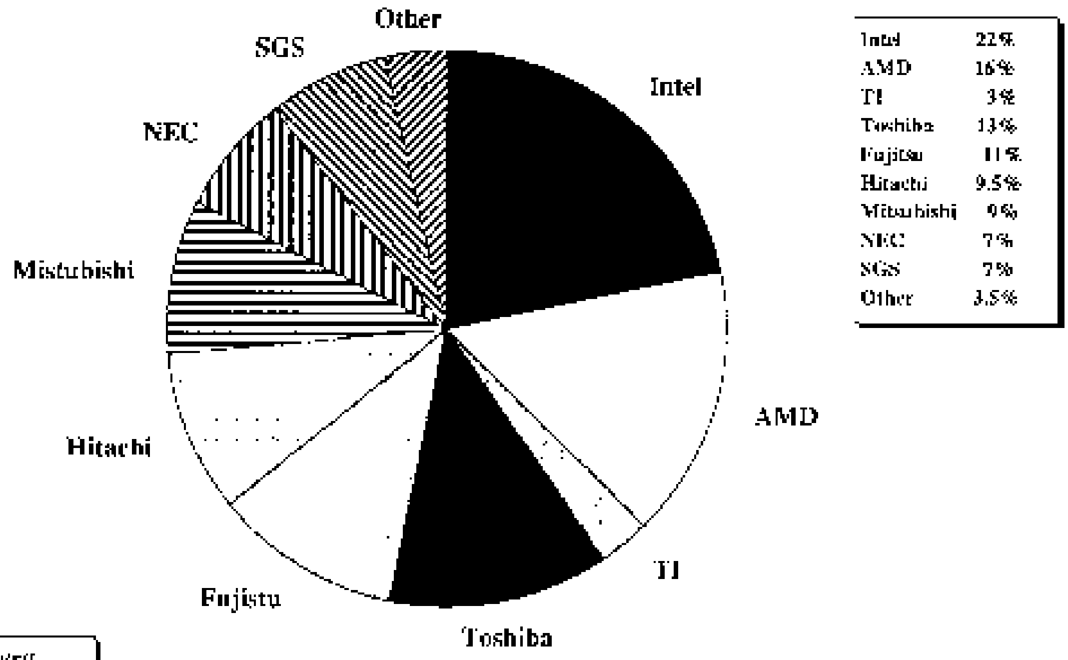
Sources: Cost Data: SIA, A Deal Is A Deal, p.64; Price Data: Average Selling Price Reported by Dataquest

Figure 8B: 1M EPROM Average Cost* and Average Selling Price



Sources: Cost Data: SIA, A Deal is A Deal, p.64; Price Data: Average Selling Price reported by Dataquest

Figure 9: 1990 1 Meg EPROM Market Share Leaders



Source: Dataquest