Chapter 5

Links Between Firms and Industries

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Industries do not standalone. They are linked with suppliers of machinery and materials in one direction and with a chain of customers in the other. How a firm or an industry handles these relations has a good deal to do with its competitive performance. In all kinds of manufacturing industries, close links and stable relations between suppliers and purchasers seem to be important factors in boosting overall performance, including productivity, quality, and innovation.

U.S. industries, on the whole, have not been strong on collaborative vertical links. The traditional relation between supplier and customer has instead been distant, even adversarial, and based mainly on price.[1] But there are signs of a trend toward more collaboration. U.S. auto companies are trying to form closer, longer-term relations with parts suppliers. Sematech, the industry-government consortium dedicated to improving manufacturing technology in semiconductors, began by strengthening ties between chipmakers and producers of the materials and equipment used to make chips. Textile companies are forging stronger links backward to fiber suppliers, forward to apparel makers, and beyond to retailers. Individual firms that have made a comeback against foreign competition use close supplier links as part of their strategy, a leading example being Xerox.

The trend toward closer links is certainly not universal. Nor is it likely that American manufacturers will ever replicate the distinctively Japanese style of close, mutually obligating bonds between parent and subsidiary companies (even in Japan the bonds are weakening somewhat). But the advantages of collaborative links, throughout an industry complex and between related industries, are increasingly appreciated.

LINKS BETWEEN MAJOR MANUFACTURERS AND SUPPLIERS

Traditionally, U.S. manufacturers have either supplied their own materials and parts (in vertically integrated companies) or, when dealing with outside suppliers, have kept them at arm's length. A common strategy has been to pit one supplier against the other and drive the hardest possible bargain on price. In offering their own goods to the next producer down the chain, the main selling point has also been price, with quality, service, and responsiveness to customers' needs taking a lesser place. This approach is not confined to the United States, but is typical in many market-oriented industrial countries.

A different pattern is common in Japan. In the world-class industries that have led Japan's strong trade performance, manufacturers generally maintain long-term, collaborative relations with their outside suppliers. They are demanding on price and equally demanding on quality and just-in-time delivery, but they also give their suppliers technical help--occasionally financial help as well—in meeting these demands. Suppliers who show they are able to satisfy the manufacturer's demands can be fairly confident of keeping the business, rather than losing out to a price-cutting competitor. This pattern is part of the overall Japanese approach of careful attention to all aspects of manufacturing, including the quality of components and supplies.

The manufacture of motor vehicles offers an exceptionally clear picture of these alternate ways of handling links with suppliers. Organization of supply is a central feature of the auto industry, since the average car or truck contains some 15,000 parts. Historically, U.S. automakers have chosen one of the two opposite approaches: either vertical integration (as practiced by General Motors, which is 70

[1] The pattern is not invariable. For example, major airlines have long had close, cooperative ties with the manufacturers of aircraft, with airline engineers taking a leading part in design and purchase decisions. However, with deregulation of the industry, the ties are loosening; airlines are cutting their engineering staffs and making purchase decisions more strictly on the basis of price. See the case study of the commercial aircraft industry in Michael L. Dertouzos, Richard K. Lester, Robert M. Solow, and the MIT Commission on Productivity, Made *in America: Regaining the Competitive Edge* (Cambridge, MA: The MIT Press, 1989).

percent integrated), or arm's-length purchase from suppliers bidding against each other (Chrysler, 25 percent integrated). Vertical integration is supposed to have the advantage of lowering barriers between supplier and main company (reducing transaction costs)--e.g., by assuring that suppliers' interests are the same as the company's, or by making it easier to transfer new technology to the supplier. The arm's-length bidding system is supposed to do a better job of keeping suppliers' prices low.

Japan's highly successful auto manufacturing industry uses the third approach, a middle way that is sometimes termed the supplier group system.[2] It consists of a pyramid, topped by the final assembler, who deals with a group of first-tier companies just below that are responsible for major components. The first-tier suppliers manage relations with the second tier, who supply individual parts and themselves often deal with third-tier groups, which may in turn reach down as far as a fourth tier of tiny firms specializing in very narrow tasks. Some of these supplier groups are tightly bound. This is especially the case with the Toyota group, composed of 225 companies that own each other's shares and lend staff and equipment from purchaser to supplier, starting with the assembler and reaching down through the various tiers. Other companies, such as Honda, have a looser structure, relying more on independent suppliers who also serve other major assemblers. But here too the relationships are close and long-term.[3]

A leading virtue of the Japanese system is that it is easier to manage than the older U.S. systems. A study for the International Motor Vehicles Program comparing General Motors procurement with Toyota's found that, despite GM's 70 percent vertical integration, and despite stringent efforts to cut back its purchasing departments, GM still had 6,000 buyers of outside components and supplies in 1987. The Toyota Motor Co., only 20 percent integrated and producing about 40 percent as many vehicles, might be expected to need as many buyers as GM but reportedly had 337.[4] These figures very likely draw an exaggerated picture of the differences, because Toyota often uses engineers as purchasing agents so that the number of its buyers is probably understated. But the disparity is so large that some of it is bound to be real, not definitional.

The answer to the seeming paradox is that, in the Toyota system and others like it, purchasing is delegated down the line. So are other responsibilities. The final assembler makes the car bodies, engines and drive trains, and integrates the system. But the first-tier suppliers are assigned the tasks of designing, engineering, and testing components, as well as producing them. Often, the supplier delivers to the assembler pre-packaged subassemblies that contain many parts (e.g., instrument panels or suspension systems). The suppliers moreover have the burdens of assuring quality and managing just-in-time delivery. What they get in return is a reliable purchaser for their particular components for the life of the vehicle model, and often beyond—subject to the understanding that they will continually reduce the component's cost while maintaining its quality. At the same time, to keep competition keen, assemblers often do business with more than one supplier of the same component.

Industries other than automating are just as wedded to the supplier group system-e. g., the manufacture of cameras (e.g., Canon), office copiers (Fuji-Xerox), personal computers and printers (NEC and Epson).[5] Figure 5-1 illustrates the supplier network for Fuji-Xerox. A rough indication of the extent of the system is that the share of Japanese

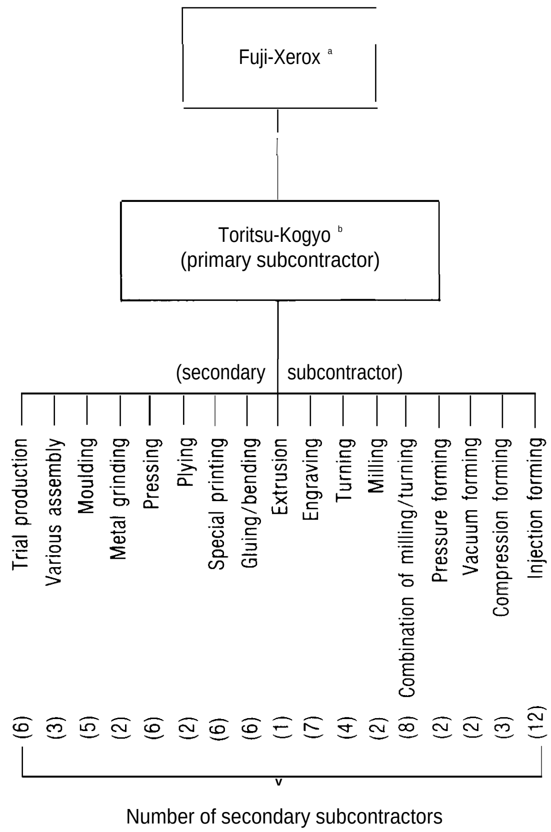
[2] The Japanesegroupsystem has been described by many authors; a comprehensive treatment of the system as practiced in the auto industry is in Michael Cusumano, *The Japanese Automobile Industry: Technology and Management at Toyota and Nissan* (Cambridge, MA: Harvard University Press, 1985), see esp. pp. 241-61. A succinct description is in James P. Womack and Daniel Roos, "Case Study: The Automotive Industry," contract report to the Office of Technology Assessment, Sept. 15, 1988; some of the material in this section on the motor vehicle industry is drawn from this report.

[3] A recent Japanese survey found that 68 percent of subcontractors had never changed their ‘‘ Pment, ’ and that 53 percent had been doing business with the same parent for 15 years or more. Chusho kigyo cho cd., *Chusho kigyo hakusho* (Small and Medium Size Enterprise White Paper) (Tokyo: Okurasho instasu kyoku, 1988), p. 61, cited in D.H. Whittaker, ‘‘New Technology in Small Japanese Enterprises: Government Assistance and Private Initiative," contract report to the Office of Technology Assessment, May 1989.

[4] Toshihiro Nishiguchi, ‘‘ Competing Systems of Automotive Components Supply: An Examination of the Japanese ‘Clustered Control’ Model and the ‘Alps’ Structure," Massachusetts Institute of Technology, International Motor Vehicles Program Working Paper, May 1987, p. 15.

[5] Ken-ichi Imai, Ikujiro Nonaka, and Hirotaka Takeuchi, "Managing the New Product Development Process: How Japanese Companies Learn and Unlearn, ‘‘ in Kim B. Clark, Robert H. Hayes, and Christopher Lorenz (eds.), *The Uneasy Alliance. Managing the Productivity-Technology Dilemma* (Boston, MA: Harvard Business School Press, 1985).

Figure 5-1-Supplier Network for Fuji-Xerox



a Has other primary subcontractors.
b Serves as subcontractor for other manufacturers.

SOURCE: Ken-Ichi Imai, Ikujiro Nonaka, and Hirotaka Takeuchi, "Managing The New Product Development Process: How Japanese Companies Learn and Unlearn," in Kim B. Clark, Robert H. Hayes, and Christopher Lorenz (eds.), *The Uneasy Alliance: Managing The Productivity Technology Dilemma* (Boston, MA: Harvard Business School Press, 1985), p. 364.

manufacturing companies using subcontracting rose from 32.5 to 37 percent from 1976 to 1981; in the electrical machinery industry, the share rose from 55 to 58 percent.[6] And subcontracting in Japan usually involves long-term relations and mutual obligations—what the Japanese call the *oyakigyo-kogaisha* relationship (literally, parent business-child company, but with connotations extending to many forms of superior-subordinate relationships).[7]

The supplier group system is doubly advantageous to the lead manufacturers. They get many of the benefits of both arm's-length subcontracting (control over costs) and of vertical integration (responsiveness to the lead company's needs). Moreover, the requirement of uniformly high quality from suppliers is part of the system of building in quality throughout the manufacturing process, rather than inspecting for defects at the end of the line. With this system quality need not cost extra, since it saves the cost of keeping large inventories of parts and requires less re-work.

Close interactions between the major manufacturer and its suppliers also helps the lead company field new models quickly, by dividing the labor of product development among many small firms with specialized skills. Shaving time off development can give a firm a crucial headstart. Firms that are first to respond to market changes and to adopt new technologies in their products open a lead that is hard for competitors to close.

In a study of the world's motor vehicle assemblers, a Harvard Business School team found that Japanese automakers take about 3.5 years to produce a new car design, compared to 5 years for American and European producers, and that the Japanese do it with half the engineering effort.[8] This takes into account the different amounts of engineering effort contributed by components suppliers in Europe, the United States, and Japan. The advantage, the study said, ''appears to lie in the strength of the Japanese supply base, and the way projects are organized and managed. Within the lead company, the main advantage lies in simultaneous rather than sequential engineering, made possible by a continuing informal dialog between people at different stages of the design process, with give-and-take in both directions. But suppliers contribute to this interactive process too. Often they take part in collective engineering and analysis of key new components 2 years before manufacture of a new model. About 1 year ahead of time, first- and second-tier suppliers

[6] Robert J. Ballon and Iwao Tomita, *The Financial Behavior of Japanese Corporations* (Tokyo and New York: Kodansha International Ltd., 1988), p. 45, citing the Ministry of international Trade and Industry, *White Paper on Small and Medium Enterprises in Japan, 1987* (Tokyo: MITI, 1987).

[7] Ibid., ch. 3. Many other authors have also described this intermediate system, between arm's-length contracting and vertical integration, in a variety of Japanese industries. For recent examples, see Nishiguchi, op. cit.; and Mari Sake, 'Neither Markets nor Hierarchies: A Comparative Study of Informal Networks in the Printed Circuit Board Industry, ' paper prepared for The First Conference of the Project 'Comparing Capitalist Economies: Variations in the Governance of Sectors," Wingspread, Wisconsin, May 1988.

[8] Kim B. Clark, W. Bruce Chew, and Takahiro Fujimoto, ''Product Development in the World Auto Industry: Strategy, Organization, Performance,' paper presented to the Brookings Institution Macroeconomics Conference, Dec. 3, 1987 (available from Graduate School of Business Administration, Harvard University).

may be brought in to run an assembly or subassembly line, to solve startup problems before actual manufacture.[9]

The supplier group system is also credited with an important role in the Japanese strategy of manufacturing a greater variety of products at lower volume than U.S.-style mass production has done, while still keeping costs competitive. This ability is particularly striking in the auto industry. When it started out in the early postwar years, Japanese auto production was, perforce, in small batches and great variety. The Japanese domestic market was small, exports were virtually nonexistent, and producers were numerous (they still are). The answer to the fragmented market and extreme competition was to develop a flexible production system within the factory. This included multi-skill training of workers and efficient layout of the factory and organization of work. It also included the supplier group system, with its collaborative engineering, just-in-time delivery, and assurance of high-quality parts and components. The result was an industry that initially succeeded in the rich U.S. market with a niche product (the well-made, economical small car), and has continued to broaden its sales appeal with frost-class entries into specialized markets (e.g., sports and luxury cars).

Today, the average annual production per model of the Japanese automakers is about 120,000, half that of U.S. producers. Since they introduce new models more often and more quickly, the lifetime production for the average Japanese model is about 500,000 units-less than one-quarter of the 2.1 million units for U.S. producers and well below the lifetime 800,000 units per model for the high-priced European specialists (BMW, Mercedes, Porsche, Jaguar, Volvo and Saab), The group supplier system is only one of the factors that make this flexibility possible, but it is a considerable one.

As for the suppliers, they also get multiple benefits from the system. Besides gaining reliable markets for their products, they often get loans of up-to-date equipment and sometimes financial help in buying it; assistance from borrowed engineers or technicians in learning how to use the equipment or organize work more efficiently; and in general a flow of advanced technology that has helped to make many first-tier suppliers first-rate industry leaders.[10] This technology transfer is not confined to the first-tier companies but frequently extends to the level of tiny family-run metalworking firms.[11]

Table 5-1 lists advantages of the subcontracting system from the participants' points of view, as reported by Japan's Small and Medium Enterprise Agency. At the top of the list, for suppliers, is a ''steady amount of orders. ' This stability sometimes extends to a change in product line. For example, one Japanese subcontractor who had worked with an electronics manufacturer for many years reported that he had changed from supplying paint and sheet metal to supplying printed circuit boards, at the customer fro's request.[12]

On the down side, the system has a high level of stress. Lead companies demand continual price reductions as well as high quality, and if a supplier fails to meet the demands, he may find his share of sales cut back (or even cut off eventually) in favor of a more compliant supplier. As noted, lead companies often have two or more firms supplying the same item, and the competition is tough. While an existing supplier may be safe from sudden shifts to a new competitor offering drastically lower prices (e.g., one electronics producer stuck with his supplier of printed circuit boards despite an offer from a newcomer of a 40 percent lower price), frequent ''requests' by the lead firm for price cuts can narrow the difference fairly quickly .13 Moreover, in a recession, the supplier is expected to make do with smaller orders, cut prices to the bone, and forgo profits. In Japan's economic downturn of 1986, profit margins for the printed circuit board industry fell from 2.5 percent of sales to 0.3 percent.[14] However, the lead company has the obligation to tighten its belt too; suppliers trust that their large customers will not squeeze them into bankruptcy.

[9] Toshihiro Nishiguchi, op. cit., p. 10.

[10] Reputable suppliers may get indirect financial benefits as well. Major manufacturers generally belong to a group that includes a large bank; loans on favorable terms from that bank are often made to a supplier on the lead manufacturer's recommendation.

[11] See ch. 6.

[12] Mari Sake, op. cit.

[13] Mari Sake, op. cit.

[14] Ibid.

Table 5-l—Main Reasons for Subcontracting, Japanese Firms, 1966

Subcontractor		Parent company	
Reasons	Percentage	Reasons	Percentage
Steady amount of orders	50.1	Know-how of contractor not held by oneself	57.6
Product design and development difficult by oneself	45.8	Efforts concentrated into best suited work	48.2
Efforts concentrated on production activities	38.7	Past business relations with and reliability of subcontractor	46.5
No worries about default or debts	27.7	Increased flexibility through size of orders	37.1
Improved reputation	26.2	Lower personnel costs and lower unit costs of products	36.5
Supply of raw materials, etc.	21.7	Small lot sizes and thus greater efficiency through production by small enterprises.	30.6
Technical assistance provided	14.7	Overly large size of own company would reduce operating rate	9.4
		Competition among subcontractors ensures high quality and lower unit price	8.8

SOURCE: Small and Medium Enterprise Agency, Survey in Division of Labor in Manufacturing Industries (Tokyo: SMEA, 1966), pp. 24-25.

Suppliers are also expected to push themselves to the limit to meet urgent needs of important customers. For example, when Fuji-Xerox changed the design of a part midway through development of a new copier, it made an "utterly insane' request for early delivery of a newly designed part which the subcontractor was able to meet only by working through the nights. The subcontractor was later rewarded with a generous payment. [15] But a more important motive for such sacrifice is the fact that the subcontractor's own future depends on the success of the lead manufacturer.

Finally, wages among subcontractors, especially in the lower tiers, are at least 25 percent lower than wages of the privileged lifetime employees of major manufacturing firms.[16] Indeed, low wages for the ''mom-and-pop' suppliers at the bottom of the pyramid has long been considered a competitive advantage of Japanese producers. An integrated company like GM could credibly claim this as a handicap--although GM presumably found advantages in vertical integration to compensate, since it competed successfully for years against Chrysler, which had a substantial discrepancy between the pay of its own employees and that of its suppliers. Recent research suggests that disparities in incomes between small and large firms are not as great as disparities in wages. The published data cover the workers' wages in small family-run companies, but not the income of the owner, who gets profits as well as wages. [17] Many of these small entrepreneurs make a good living. One investigator of subcontracting firms in the Japanese auto industry reported that owners of small firms made about 10 million yen a year ($71,000) on average, compared to 5 million yen for people of the same age and same high school education who work for big companies. In interviews with over 100 of these small subcontractors, the author found them "remarkably confident and satisfied despite their seemingly unstable position in the industrial economy."[18]

In any case, many American managers now seem persuaded that the system of buying from autonomous, but closely linked suppliers, offers benefits quite apart from wage differentials. The big three automakers are making moves toward adopting the group supplier system, or parts of it. The GM-Toyota joint venture, New United Motor Manufacturing, Inc. (NUMMI), has adopted the system successfully, largely with North American suppliers. It took time. At first, NUMMI found three times as many defects in the parts supplied by North American companies as in those coming from Japanese companies. But Toyota and NUMMI engineers worked with the 70 North American suppliers, and 4 years after the 1984

[15] Imai, Nonaka, and Takeuchi, op. cit., p. 371.

[16] Nominally, wages in establishments with 5 to 29 workers are only 57 percent of wages in firms with 500 or more workers. Controlling fOr differences in occupational employment eliminates about 20 percentage points of the 43 percent difference. The discrepancy has been growing; wages in the smallest establishments were 63 percent of those in the largest in 1965, but dropped to 57 percent in 1983. (OTA interview with officials of the National Institute of Education and Vocational Research, Tokyo, Mar. 15, 1989.)

[17] Toshihiro Nishiguchi, op. cit.

[18] Ibid., p. 21.

startup these suppliers were as good in cost, quality, and delivery times as their Japanese counterparts.[19]

For U.S. companies in general, both lead companies and suppliers, the changes involved in moving to the supplier group system are great and consequently slow. It means going from l-year contracts with specifications and drawings (sometimes dies and tooling as well) provided by the assembler to multi-year, less formal arrangements, in which suppliers are expected to help design and develop parts, continuously improve them, and respond quickly to requested changes during the model run.[20] It also means requiring suppliers to deliver just the right number of defect-free parts precisely when the assembler needs them. The just-in-time delivery system depends on getting high-quality parts, since there are no stacks of backup parts to replace defective ones. When the system works, it saves costs in storage, handling, end-of-the-line inspection, rework, and repair after sale, and the quality built in at every stage of supply up the pyramid leads to a reliable product and customer satisfaction. But the system also requires high competence on the part of suppliers and a good working relationship between assembler and suppliers. These attributes are not easy to develop overnight.

According to the General Accounting Office (GAO), Japanese auto assemblers operating in the United States impose on suppliers the rigorous expectations described above. (GAO reports that U.S. firms are also beginning to expect the same kind of quality, prompt delivery, and engineering capabilities from their suppliers.) A good many U.S. suppliers are having trouble meeting the expectations. Japanese supplier firms, accustomed to working in this way and also benefiting from longtime relationships with Toyota, Nissan, Honda, or Mazda in Japan, often have the advantage. The number of Japanese suppliers in America (some of them in joint ventures with U.S. fins) is growing fast. Of 104 Japanese-affiliated suppliers operating in the United States in August 1987, 102 answered queries by GAO. Of these, 60 had opened up for business in America since January 1981; 23 were established from 1970 to 1980, and 19 before 1970.

Some U.S. suppliers have succeeded with the Japanese transplant automakers. Of 30 representative firms GAO selected for interviews, 15 had done business with at least one of the Japanese assemblers—some in joint ventures with Japanese supplier firms. Most of these U.S. firms found big differences in the way the Japanese assemblers operated, compared with their American counterparts. The Japanese companies not only gave the suppliers added responsibilities but, several said, also kept in closer contact. Where the U.S. assemblers would send a few people on an occasional courtesy visit, the Japanese turned up often, bringing a wide range of staff to give the suppliers' operations a complete evaluation. One trim and body parts supplier said the Japanese assembler he deals with calls every day to consult on defects. A steelmaker said the Japanese company visits were "preventative" where the American company's were ''reactive. ' Most of the U.S. suppliers doing business with the Japanese transplant automakers rated the results positively. They cited benefits of greater efficiency, better quality control, and more attention to process and product improvements. Some said the experience made them more competitive, and that they were now demanding more from their own suppliers. And some noted that U.S. automakers are adopting more and more of the Japanese practices.

These positive comments came from the firms that had succeeded in supplying the Japanese companies. From less successful firms came comments that it is hard to overcome the longstanding ties between Japanese assemblers and suppliers, and that U.S. firms are at a disadvantage in culture and language. These companies feared growing competition from Japanese-affiliated suppliers now locating in the United States. Although the Japanese automakers have stated that they intend to increase the U.S. content of their cars and trucks from about 50 percent in 1987 to about 70 percent by the early 1990s, it is not clear that "U.S. content" means the products of U.S.-owned firms.[21]

[19]John F. Krafcik, ''A New Diet for U.S. Manufacturing, " *Technology Review,* Jan. 28, 1989, pp. 31-32.

[20]The following discussion of U.S. and Japanese firms supplying automakers in the United States (both U. S.- and Japanese-owned) is based mostly on U.S. General Accounting Office, *Foreign investment: Growing Japanese Presence in the U.S. Auto Industry,* GAO/NSIAD-88-1 1, March 1988.

[21]According to GAO, U.S. automakers reported that the domestic content of their cars and trucks was 86 to over 99 percent, depending on the model, in 1986; the average for the industry was about 90 percent. These figures applied to autos made in North America, including Canada, and did not include foreign-made cars with a U.S. nameplate ("captives" such as the Dodge Colt, which is Mitsubishi-made). U.S. automakers were expected to increase the foreign content of their cars to about 17 percent by 1990, GAO said.

A fundamental change in outlook would have to evolve if Japanese-style supplier relations were to become the norm rather than the exception in U.S. manufacturing. It is longstanding custom for American manufacturers to discourage-even forbid—design engineers from developing close relations with suppliers. Direct approaches to suppliers are known as "going around the purchasing department,' and are against company rules. Purchasing agents themselves are frequently reassigned to different types of supplies, so they won't develop overly cozy relations with suppliers. The ideas behind all this are, frost, that maintaining arm's-length, impersonal, strictly contract-based relations with suppliers is the best way to get a good price and keep costs down; and second, that it is unfair to give any supplier a privileged position and deny the others an equal chance. Some company officials even believe they might be subject to lawsuits if suppliers were deprived of the chance to bid for contracts.

For suppliers themselves, the Japanese-style system has distinct drawbacks as well as strong points. While some may welcome the demands for constantly improving performance combined with help in achieving it, others find the system entirely too stressful. Moreover, the American tradition of rugged individualism exerts a pull against close bonds with customer fins. Some small companies think that if their quality and delivery times improve, they should be rewarded with higher prices-not with a long-term tie to a demanding customer. Some see such ties as threatening to their independence. They would prefer to take their chances in the bidding battle rather than find themselves beholden to too few major customers. The Japanese system does make for heavier dependence on a few customers—— only tolerable, perhaps, in a situation where many suppliers trade with their major customers for 15 or 20 years .22

A Japanese engineer who has observed relations between large and small companies in both Japan and the United States put it this way. In Japan, small companies making parts for computers or copiers or facsimile machines are very conscious that they are in the office automation business. They carefully monitor the price they have to stay under so that their customers, the companies that assembles the machines, can be competitive. In the United States, small companies are not so conscious of being part of a whole.

Dependence may be lessening even in Japan; as economic growth has slowed, some lead companies have actively encouraged their suppliers to seek other customers. The bonds of long-term relations are still strong however. It must be remembered that the system has roots in the centuries-old tradition of mutual obligation, and that it developed over decades in the postwar period when it suited the needs of all parties quite well. The major manufacturers were growing too fast to do all their own work; the smaller companies were eager to take part in the growth, and also to get access to modern technology at a time when foreign currency was scarce and government restrictions allowed only a few firms to import the latest machinery from Europe and America. Today, the parties to the bargain still seem satisfied, on the whole, that it is working to the advantage of all.[23]

LINKS BETWEEN SEGMENTS OF AN INDUSTRY COMPLEX

A variant of the strategy of close relations between major manufacturers and their suppliers is close links between different segments of an industry complex--e.g., between the manufacturers of chemical fibers, textile producers, apparel makers, and retail clothing businesses. There is more than a shade of difference in this variant. A chain of more or less independent industries selling to and buying

22A 1983 survey of 1,54.() Japanese subcontractors in the metal/machining industry found that, on average, these firms relied on one large customer (parent firm) for 60 to 65 percent of their business. (D.H. Whittaker, op. cit.) Mari Sako found in her study of printed circuit board suppliers in Japan and the United Kingdom (where customer-supplier practices are similar to those in the United States) that the Japanese suppliers depended much more heavily on fewer customers. Comparing companies of similar size,Sako found that in Britain orders from the largest customer made up 6 to 25 percent of suppliers' total sales. In Japan, the largest customer accounted for 15 to 85 percent of the supplier's total sales. (Mari Sake, op. cit.)

23Korea and Taiwan, which are following the Japanese model of export-led growth in many ways, have not emulated the supplier group system. Korea's *chaebol are* industrial empires, typically doing business in a few related sectors, under the ownership and management of a founding father and his heirs. They do not rely on long-term, stable relations with small subcontractors but rather buy or start up new firms to meet their needs. In Taiwan, business groups are much less prominent than in Japan or Korea. The groups that do exist arc made up of rather small firms in different economic sectors, with horizontal rather than vertical relations; the same people or their relatives hold management positions in the different fins. Relations with subcontractors are not particularly close or long-lasting. (Gary G. Hamilton, Marco Orru, and Nicole Woolsey Biggart, ''Enterprise Groups in East Asia: An Organizational Analysis, ' *Shoken Keizai*, September 1987.)

from each other differs considerably from the superior-subordinate relation of a lead manufacturer and its network of suppliers. Nevertheless, even among the nominally independent members of an industry complex, a purchaser who has attractive alternatives for material supplies wields more power than the supplier. In the case of the fiber-textile-apparel complex, it is designers and retailers who hold this power. They can buy anywhere in the world. Increasingly, in the past quarter-century, they have done so. Imports account for well over one-third of what Americans spend on apparel.[24]

In nearly all high-wage countries, the textile and apparel industries face a tough challenge from poor countries. Apparel manufacture is labor-intensive. Modern textile production is less so, but the capital requirements are relatively modest—well within the means of newly industrializing countries (e.g., Taiwan, Korea) and not out of reach for some poorer ones (China). The textile-apparel industries that seem to do best in high-wage countries are those with close ties between industry segments, where firms in the supplier industry focus their efforts on responding to customers' needs.

In the United States, textile producers and apparel makers have traditionally had standoffish or even hostile relations.[25] The main concern of textile producers was to mass-produce with high-speed equipment, rather than deal individually with customers' needs. Apparel makers, if they were big enough, treated their textile suppliers as interchangeable and disposable, bargaining with numerous firms to drive the price down. This situation has begun to change. Industry leaders are realizing that closer links, from fiber production through retailing, can lower costs, lend stability to all parts of the complex, and give an edge to domestic producers.

The Quick Response system was devised by U.S. industry leaders to foster these tighter links and capitalize on the advantage of being close geographically to the big American retail market,[26] Imports (most of which are from low-wage countries) have the attraction of lower prices;[27] but there are also extra costs in doing business with importers. Besides the obvious ones—transportation, travel overseas, advance letters of credit, and extra paperwork-the long leadtimes usually involved in overseas purchases also mean extra cost. When retailers order a year ahead of time they pay carrying costs for large inventories; they lose profits when they have to mark down unsold goods at the end of the season; and they pay still more in lost sales when items the customers want are out of stock. One industry expert estimates that these costs add up to 25 percent of the value of net retail sales.[28]

The Quick Response system uses just-in-time principles to reduce these costs. It allows the retailer to start the season with a wide but shallow selection, and when stocks get low, to re-order and get fast delivery. About 80 percent of retail apparel business is in items that have a shelf life of only 10 to ***20*** weeks, either because they are ''fashion" items in styles that are quickly changed or because they are seasonal. Quick Response is most obviously a useful strategy in these lines. However, some producers of textiles for non-seasonal products, such as bedding or men's underwear, are finding that close, stable ties with their customers make it possible to cut inventories nearly to zero by just-in-time management, and thus to save costs.

24OTA's estimate of import penetration in apparel is 36 percent for 1987. It is based on dollar value, and includes freight, insurance, and import duties; shoes are not included. Other dollar value estimates of impons, which include the costs of transportation within the United States and other extras, put the import penetration ratio for clothing at 57.5 percent. See "Import Penetration in the Apparel Industry: A Technical Study,' prepared for the Fiber, Fabric and Apparel Coalition for Trade, September 1988. Import penetration is less for textiles, about 9 percent. (The apparently low figure for textile imports are misleading. Over the past 30 years, many foreign producers have switched from textile to apparel exports, because apparel has more value added. The quotas limiting imports combine textiles and apparel; textiles embodied in the apparel are not counted separately.) The combined import penetration ratio for textiles and apparel was 25 percent in 1987, according to OTA's estimate.

25This is usually not true of textile producers and industrial consumers, such as auto companies buying seat cover fabrics, or hotel chains buying carpet. Typically, U.S. textile producers keep close ties with these industrial customers, and are very responsive to their needs. This is probably one reason for the greater success of the industrial fabrics sector, compared with the apparel fabrics sector, in fending off imports.

26A consulting firm, Kurt Salmon Associates helped to devise the plan; the DuPont chemical company and Roger Milliken of the Milliken textile company have been leading champions. DuPont is an important producer of textile fibers.

27The top four textile and apparel exporters t. the United States—China, Taiwan, Korea, and Hong Kong have textile wages ranging from about 2 to 23 percent of U.S. wages; the next two-Japan and Italy-now have textile wages 30 to 40 percent above those of United States, since the fall of the dollar.

28Kurt Salmon Associates, *The KSA Perspective (New* York, NY: January 1986).

To make Quick Response work, each of the industry segments upstream not only has to cut response time in its own operations but also needs to cooperate with the purchaser or supplier next in line. The example of Greenwood Mills, a large textile firm specializing in denim, is illustrative. Until a few years ago, Greenwood bought fiber from four different suppliers, shopping around to drive the price down. Greenwood's biggest customers followed the same tactics, shifting orders among eight or nine suppliers on the basis of lowest price.

Greenwood and its suppliers and customers have since adopted a more collaborative way of saving costs. Greenwood now buys fiber from just two suppliers, who offer quality, service, and guaranteed delivery times in return for assurance of a long-term relationship. Using this system, Greenwood has cut inventories from 3 weeks to a fraction of a week and is able to hold $40 million less in stock. In the same way, Greenwood's two biggest customers are now, by mutual agreement, reliable long-term purchasers. Greenwood takes the responsibility of loading denim into the trucks in sequence so that colors always match, marking the cuts electronically, and delivering so quickly and reliably that one jeans maker cut inventory from 4 weeks to 3 days and the other got rid of its warehouse. The denim is delivered directly to the sewing room.[29]

The heart of Quick Response is responsiveness and interaction with customer firms. Another example comes from the Dan River textile mill, a company that concentrates on making high-quality apparel fabrics and emphasizes close customer relations. Individual looms at Dan River are marked for production for specified customers. And a Dan River representative was on the floor at one shirtmaker's plant so often that he was mistaken for a new employee.

A major achievement in the Quick Response program was inter-industry adoption of a common bar code standard. This allows electronic communication between retailers and producers all the way back through the supply chain. When and if the system is widely adopted, a textile mill, say, could start preparing anew order to send to apparel makers on the basis of electronic data passed back automatically from department store sales.

The close, responsive inter-industry links just now being developed in the United States have long been a feature of the Italian, Japanese, and German textile-apparel industries-the three high-wage countries that are usually considered the most successful in these industries. This is not to say that close linkages are a guarantor of success. All these industries have other features in their favor. For example, the Italian and Japanese industries benefit from a dense network of technical, organizational and financial support, private and public. The German industry has the advantage of an excellent century-old vocational education system. All three textile industries (and the U.S. industry as well) are well-equipped with modern machinery. None of these industries, even the best, is invulnerable to competition from low-wage countries. But it seems clear that suppliers' ability to respond quickly to the needs of their customers and purchasers' willingness to form stable, cooperative relations with their suppliers are part of the mix that makes these industries more competitive, and helps them to survive without constantly escalating trade protection.

LINKS BETWEEN MAJOR MANUFACTURERS AND CAPITAL EQUIPMENT PRODUCERS

A special case of linkage with suppliers is the relation between lead manufacturing companies and the firms that make production equipment for the industry. Perhaps even more than suppliers of parts and components, makers of capital equipment depend for their success on close relations with the manufacturers down the line who are their customers. In the semiconductor industry, for example, customer firms (the chipmakers) were the source of two-thirds of the ideas for advances in production equipment in the last few years.[30]

Customer firms, in turn, benefit from easy and continuing exchanges with the makers of their production machinery. Sometimes they can achieve this with foreign manufacturers, as seems to be the case in textile manufacture. The virtual disappearance of U.S. firms from production of the most important kinds of textile machinery is apparently not crippling to textile producers. But in a rapidly

[29] OTA interview with Thomas O'Gorman, President, Greenwood Mills, Dec. 11, 1987.

[30] Eric von Hip@, *The Sources of Innovation* (New York, NY: Oxford University Press, 1988), p. 4, table 1-1.

advancing high-technology industry, close links can be crucial. Already, U.S. semiconductor manufacturers are at something of a disadvantage because U.S. equipment makers have lost out to Japanese rivals, and the handicap could become greater.

The story of the U.S. textile machinery industry illustrates the dependence of equipment makers on close ties with their customers, The industry's precipitous decline was due largely to its failure to respond to customers' needs. In 1960, American makers of spinning, weaving, and knitting machinery dominated the U.S. market, accounting for 93 percent of sales. By 1986, their share was 42 percent, most of it in spare parts and ancillary machinery. Several leading firms in the industry were organized in the traditional Ford manner for mass production, with semi-skilled workers on the assembly line turning out long runs of limited kinds of machinery. The attitude of these companies toward their customers was, "This is what we make; how many do you want?"[31]

The merger mania of the 1960s also played a part in the industry's decline. During that decade, all the Big Five U.S. textile machinery firms and many smaller ones sold out to conglomerates. Rockwell International, for example, not only bought Draper, the leading U.S. manufacturer of looms, but also smaller companies such as the Textile Machine Works of Reading, PA, which made knitting machinery. Some of these companies had built their businesses on a solid tradition of close relations and good service to their customers. But the new conglomerate owners lacked both technical knowledge of the business and interest in serving individual customers.

Scanty spending on research and development was another major cause of the deline, with U.S. producers lagging well behind the R&D spending of competitors in Europe and Japan. When the American textile machinery industry was seriously challenged in the 1970s by innovative, responsive European and Japanese manufacturers, willing and able to make a wide range of sophisticated machines, it lost.

According to people in the textile industry, the retreat of U.S. textile machinery makers from the biggest part of the field (spinning, weaving, and knitting equipment) is not a serious technical handicap. They say that their German, Swiss, Italian, and Japanese suppliers keep improving equipment in response to their needs, and that service (especially from the Japanese) is outstanding. The main problem in dealing with foreign suppliers, as of the late 1980s, was the fall of the dollar, which made new equipment and parts suddenly much more expensive.

Semiconductor producers are faring worse. Japanese firms are now the world leaders in making the equipment that is most critical to chip production. According to industry sources, Nikon was not selling its leading edge model of this equipment to U.S. chipmakers in 1989, though the model was already widely used in Japan.[32]

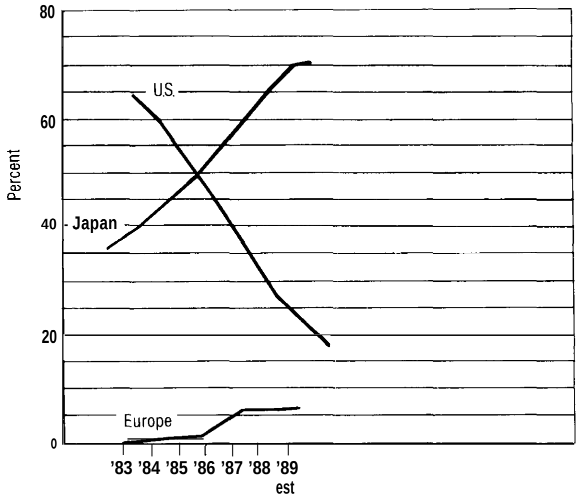
As recently as 1979, U.S. firms dominated the market for semiconductor production equipment, accounting for 79 percent of world sales. By 1989, the U.S. share was down to 47 percent and still dropping[33] (figures 5-2,5-3, and 5-4). A central part of chipmaking is the fabrication of wafers, the 2- to 8-inch silicon disks on which dozens to hundreds of individual chips are made. The most vital piece of wafer fabrication equipment is the step and repeat aligner, or stepper, which uses ultraviolet light to project an outline of the chips' circuit on the wafer; the circuit is then etched in an acid bath or reactive gas. An American firm, GCA, was first to commercialize a stepper, and it dominated the field until the early 1980s. Nikon first pulled ahead in 1983. Today, GCA (which was bought by General Signal in 1988) is out of the Japanese market, has about 5 percent market share in Europe and 20 percent in the United States. Nikon now occupies a commanding position (table 5-2). It was Nikon's latest and best stepper, the G-body, that was unavailable to U.S. firms in 1989.

[31] Charles F. Sabel, Gary Herrigel, Richard Kazis, and Richard Deeg, "How To Keep Mature Industries Innovative," *Technology Review*, Apr. 28, 1987.

[32] Principal sources for the following section are OTA'S review of the literature and interviews with leaders in the semiconductor and allied industries, and with officials of the Sematech consortium; other sources include Industry and Trade Strategies, ''The U.S. Electronic Industry Complex,' contractor report to the Office of Technology Assessment, October 1988; William F. Finan and Jeffrey Frey, ''Study of the Management of Microelectronics-Related Research and Development in Japan,' contractor report to the Office of Technology Assessment, November 1988.

[33] VLSI Research, Inc., personal communication, Jan. 5,1990.

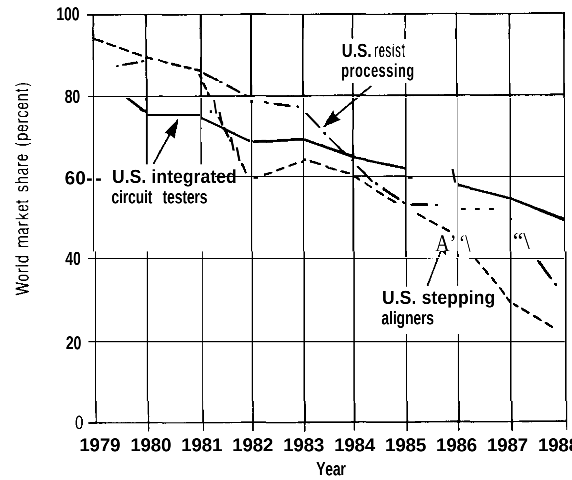
Figure 5-2--Shift in Market Shares for Wafer Steppers



NOTE: The wafer stepper is a device central to manufacturing semiconductors.

SOURCE: VLSI Research, Inc.

Figure 5-3--U.S. Market Shares of Selected Semiconductor Equipment



SOURCE: VLSI Research, Inc.

Of the several reasons why Japanese firms have bested U.S. equipment makers, a leading one is that U.S. chipmakers were themselves losing out to the Japanese competition.[34] Japanese firms began to spend more on capital equipment than their U.S. rivals in 1983, and continued to outspend American firms throughout the industry's worldwide slump in 1985 -86.[35] Increasingly during this build-up, Japanese chipmakers bought Japanese-made production equipment—in the case of steppers, overwhelmingly from Nikon. GCA, which had geared up to produce 500 to 600 steppers (at $1 million apiece) in 1985, sold barely 100 for the year, and wound up losing $94 million. Financially weakened, suffering delays in delivery of lenses from the German firm Carl Zeiss (Nikon made its own lenses), and making a stepper that was no longer clearly the world's best, GCA never recovered.[36]

How Nikon caught up with GCA technologically is another part of the story. Close relations between the maker of production equipment and the customer using it played an important role. The Nikon stepper was an outgrowth of the very large-scale integration (VLSI) project which MITI directed from 1976 to 1979. The goal of this cooperative industry-government project was to help Japanese companies master the technology for making the newest generation of semiconductors and, more broadly, to encourage the national move toward more knowledge-intensive industries.

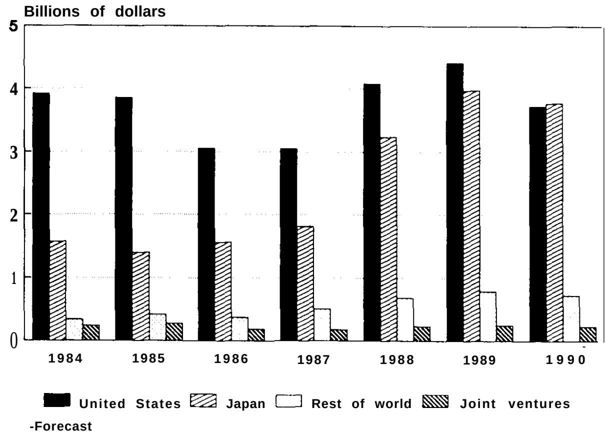
The emphasis of the VLSI project was on the manufacturing process. One-third to one-half of the budget went for purchase of equipment (including a GCA stepper), and the five chipmakers who were the

[34] In 1981, U.S. merchant companies (those that produce chips for the open market, not just for their own internal use) shared the big important market for dynamic random access memory chips (DRAMs) equally with Japanese firms. By 1988, U.S. firms had 8 percent of the world merchant DRAM market (this excludes chips made by integrated firms such as IBM for their own internal use), Japanese firms had 87 percent, and most of the rest was divided between West Germany and Korea.

[35] Dataquest figures, as shown in *The Semiconductor Industry*, report of a Federal Interagency Staff Working Group (Washington, DC: National Science Foundation, 1987), p. 28, chart 24. The data cover U.S. merchant (but not captive) producers. The rate of capital spending by Japanese companies (i.e., spending on plant and equipment as a percent of revenues in the integrated circuit business) has been higher than the U.S. rate since 1982. For years before 1981, the data on rates of capital spending are in conflict. OTA's data for 11 U.S. merchant producers and 11 or 12 Japanese producers, show that the Japanese rate was higher from 1973 to 1980, and nearly the same in 1981; see U.S. Congress, Office of Technology Assessment, *International Competitiveness in Electronics*, OTA-ISC-200 (Springfield, VA: National Technical Information Service, November 1983), p. 274. According to Dataquest, the Japanese rate was about equal to the U.S. rate from 1977 through 1981 but in 1982 and thereafter was higher; see *The Semiconductor Industry*, op. cit.

[36] According t. U.S. industry sources, the GCA stepper has better focus and more precise alignment than the Nikon—but only when engineers set it up. The Nikon stepper is more robust and requires far less set-up time. It can run well day after day with little adjustment, and therefore is much superior in throughput (an important consideration for mass production of commodity chips).

Figure 5-4--World Semiconductor Equipment Sales



SOURCE: VLSI Research, Inc.

main participants from industry worked hand in glove with equipment makers. The project managers selected Nikon to develop a made-in-Japan wafer stepper—a logical choice since Nikon already had a fine reputation as a maker of precision optical equipment, cameras and lenses, and also precision mechanical measuring instruments. Toshiba, the first Japanese company to have used GCA steppers on a production line, was chosen to work with Nikon on behalf of all the member companies.

The collaboration was extraordinarily close. According to a GCA engineer familiar with the effort, Toshiba set performance specifications but did not provide a design. Instead, Toshiba engineers reviewed all details of development, manufacture, and testing; provided technical help in design concepts, electronics, and materials and components selection; and in the process visited Nikon several times a week.[37] The result was a stepper which, though not radically different from GCA's, gained the reputation of being more reliable.

The close relation between vendors and users was not unique to the VLSI project. It is characteristic of the Japanese semiconductor industry, and remains a potent factor in the industry's success. The same engineers who oversee supplier companies' development of a new piece of equipment are then responsible for putting it to work on the production line, where their familiarity with it pays off in rapid achievement of high productivity and quality. This kind of collaboration is largely missing in the U.S. semiconductor industry. According to officials of Sematech, the U.S. industry-government consortium that is working on generic improvements in the semiconductor manufacturing process, the lack of close relations between equipment producers and chipmakers is a serious handicap. The consortium has given top priority to improving those relations, and to developing a full range of high-quality, reliable, affordable equipment and materials for the U.S. semiconductor industry.

Some firms-notably big ones like IBM and AT&T—have worked closely with equipment producers. But the merchant firms (those that sell chips on the open market rather than producing chips largely for their own use) have typically had arm's-length relations with their equipment suppliers. Sometimes the relations are downright distrustful; new equipment firms are often started by executives defecting from companies that manufacture chips or from other equipment firms. The Japanese firms' habit of collaboration extends to their American as well as their Japanese suppliers. Spokesmen for GCA noted that their Japanese customers were more demanding than American fins, asking for more fine-tuning and changes in the equipment they bought. But they were also more helpful in making suggestions for improving the equipment.[38]

It is worth repeating that vendor-user relations were not the only factor in Nikon's (and later Canon's) emergence as world leaders in photolithographic equipment.[39] The nearly instant preference Japanese semiconductor firms gave to the Nikon stepper, combined with the large investments in new equipment that these firms made through the mid-1980s, were critically important. In 1981, GCA had 95 percent of the Japanese market. The next year, it had 40 percent. Today it has next to nothing. Toshiba took the Nikon stepper as soon as it was out, in April 1981. NEC followed in early 1982 when

37 Finan and Frey, op. cit., citing Jon Sigurdson, "Industry and State Partnership in Japan: The VLSI Project," Discussion Paper No. 168 (Lund, Sweden: Research Policy Institute, 1986), p. 48.

38 OTA interview with GCA.

39 When Nikon first brought out its stepper, it was the only Japan~e~ producer; Croon stuck to making the older process aligner. Later, 8s GCA weakened, Canon entered the stepper market.

Table 5-2—Top Ten Semiconductor Equipment Suppliers, World Sales
(millions of dollars)

1982		1988	
Perkin-Elmer	$162	*Nikon*	*$521*
Varian	100	*Tokyo Electron (TEL)*	*508*
Schlumberger	96	*Advantest*	*385*
Takeda Riken(Advantest)	*84*	Applied Materials	382
Applied Materials	84	General Signal	375
Eaton	80	Canon	290
Teradyne	79	Varian	211
Canon	*78*	Perkin-Elmer	205
General Signal	77	Teradyne	190
Nikon	*58*	LTX	180

(Japanese Firms Italicized)
SOURCE: VLSI Research, Inc.

prices offered by the two rivals, after intense competition, were equal. NEC said its decision in favor of Nikon was based on technical superiority, availability of local service, and early delivery. Then, when semiconductor sales nosedived in 1985, U.S. chipmakers canceled their orders for GCA steppers—a near mortal blow to a company that had just invested heavily to expand capacity.

The troubled condition of Perkin-Elmer's semiconductor equipment division, a major U.S. supplier of photolithographic equipment, underscores the point that other factors besides relations with customers are important to success in the semiconductor equipment business. For over 20 years, IBM worked closely with Perkin-Elmer on various kinds of equipment (though not the stepper, which Perkin-Elmer effectively ceded to GCA). Recently, with IBM's financial and technical help, the company developed an advanced step-and-scan machine, the MicraScan, that is said to be a technological wonder, with the potential to vault over the Japanese competition.[40] Yet despite Perkin-Elmer's technical abilities, and despite its close-working relationship with IBM, its semiconductor equipment division was a financial loser in the 3 years 1987-89 (the main part of the company's business is in scientific instruments).[41] In April 1989, Perkin-Elmer offered its semiconductor equipment division for sale.

One reason for Perkin-Elmer's decision to bow out is the heavy spending for technology development that the fast-moving semiconductor business demands; new generations of both chips and equipment appear about every 3 years. Perkin-Elmer (and IBM) spent $100 million in 4 years to develop the MicraScan, and faced costs of $50 to $100 million more to refine and update the equipment. The high cost of capital and pressures for short-term profits in the United States add to the burden of making continuing high investments in advancing technology.[42] Nikon and Canon, Perkin-Elmer's Japanese competitors, have the advantage of easier access to low-cost capital and less pressure to show short-term profit; and both these firms excel in engineering and manufacture.

IBM declined to buy Perkin-Elmer's semiconductor equipment division, on grounds that the expertise for running a toolmaking business was outside its area of competence. No other U.S. buyers had come forward by the end of the year. Nikon; which has both the technical and financial resources to run the company, was the leading suitor but then backed off, apparently because of U.S. political objections to the sale.

The erosion of leadership in production equipment is already a handicap for the U.S. semiconduc-

[40]According to VLSI Research, a consulting firm that specializes in semiconductor equipment, Perkin-Elmer's new machine has a 3- to 4-year lead on all the competition, including Nikon and Canon. Alan Cane, "Chips Are Down for Perkin-Elmer," *Financial Times*, Dec. 7, 1989, p. 21; see also Andrew Pollack, "The Challenge of Keeping U.S. Technology at Home," *The New York Times*, Dec. 10, 1989, p. 1.

[41]The division had revenues of $190 million and operating losses and charges against earnings of $200 million in the three years, according to an analyst with Shearson Lehman Hutton, Inc. (Pollack, op. cit.) The Perkin-Elmer company as a whole lost money in 1987 but made a profit in 1988.

[42]See ch. 3 for a discussion of the U.S. financial environment and its effect on technology development.

[43]Korean producers, with their low-cost labor, are a bigger threat to Japan in 1-megabit memory chips than U.S. manufacturers, and the Koreans are reported to be worried that their access to Japanese equipment may be restricted. (David E. Sanger, "South Korea's High Tech Miracle," *The New York Times*, Dec. 9, 1988, p. D1.)

tor industry, at least in wafer fabrication.[43] (American companies are apparently able to buy some other kinds of Japanese-made production equipment, such as automatic assembly and testing equipment, on fairly equal terms with Japanese chipmakers.) The situation could deteriorate. Microelectronics is one of the world's most dynamic industries. Chipmakers in the nation where critical new technology in wafer fabrication is first developed will almost certainly be the frost to use it, and thus will gain a vital advantage. X-ray lithography is a strong candidate for the next step, and in this emerging technology, the Japanese are well ahead.

Photolithographic steppers, used to etch today's l-megabit chips, can go up as far as 16-megabits, but the chips of the late 1990s and the early 21st century (64 megabits and beyond) will have circuitry with lines too fine for etching even by ultraviolet light. X-rays, with their shorter wave length, have much greater potential. Ultimately, chips made with X-ray technology might be able to store 1,000 times as much data as the current l-megabit chip.

Development of X-ray lithography is expensive. The Sematech consortium, for example, had to rule out extensive work on the technology because its funds-about $200 million a year over 5 years—would not stretch that far. In Japan, the half dozen leading chipmakers, several supplier firms, and the officially privatized (but still mostly government-owned) Nippon Telegraph & Telephone (NTT) were all involved in a MITI-led program to develop various aspects of the X-ray technology. In the late 1980s, the Japanese effort was outspending American efforts at least five to one, and several firms were engaged in developing a compact synchrotrons to generate X-rays at the right wave-length and intensity, at commercially acceptable costs.[44] In Japan, in 1989, ten compact synchrotrons were under construction or already at work on experimental projects, and five more were on the drawing boards. Development of a compact synchrotrons was also far along in Germany; government funds have helped support the Siemens company in its development. In the United States, only IBM was constructing a commercial-type synchrotrons, and the cost was straining even its resources. IBM invited other U.S. chipmakers to participate in the effort, and Motorola signed on in late 1989.

Commercial use of X-ray technology may very well come about in the 1990s.[45] If it does, the first commercial use will most likely be in Japan, giving that country's semiconductor producers a big lead in a new round of world competition. As the Japanese semiconductor industry itself has shown, it is possible to catchup even when one is far behind. The United States has yet to demonstrate this ability, although projects such as Sematech are a move in this direction.

INTERNAL LINKS: VERTICAL INTEGRATION, PRODUCT DIVERSITY, AND LARGE SIZE

Japanese firms are the world's leading producers of semiconductors, with 45 percent of the world market in 1989. U.S. companies, which held 53 percent in 1984, were down to 42 percent and declining[46] (see figure 5-5). Six of the world's top 10 companies in sales of semiconductors on the open market are Japanese, and all of them are large, stable, integrated electronics firms that make everything from chips to computers and consumer electronics. They make more chips than they need and sell the

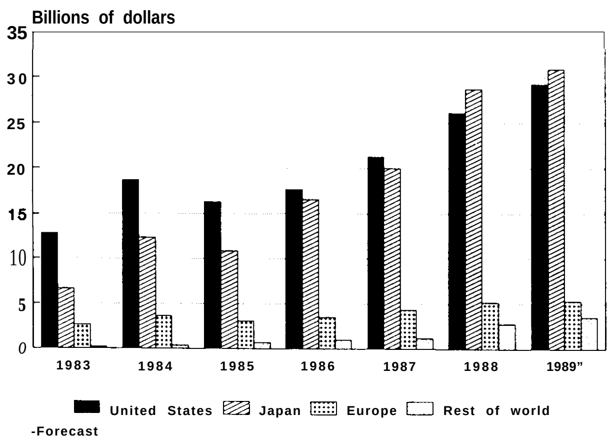
43 Korean producers, with their low-cost labor, arc a bigger threat to Japan in l-megabit memory chips than U.S. manufacturers, and the Koreans are reported to be worried that their access to Japanese equipment may be restricted. (David E Sanger, *'South Korea's High Tech Miracle,' *The New York Times*, Dec. 9, 1988, p. D1.)

44 The Japanese program had spent $500 to $750 million by late 1988, and planned to spend $200 million more; comparable figures for the United States were $50 to $100 million already spent, and $100 million planned. (John Markoff, "Experts Warn of U.S. Lag in Vital Chip Technology, " *The New York Times*, Dec. 12, 1988, p. 1.) A technology that generates X-rays by pulsed laser sources is a possible alternative to the synchrotrons, slower but perhaps more practical. Japanese R&D is also pursuing this possibility.

45 Optical (ultra-violet) lithography may last a while longer, however; Sematech is betting that it will, and is putting much of its effort into stretching the technology to its farthest limits. The history of the semiconductor industry shows that technologies sometimes last longer than expected, For example, several Japanese companies got a headstart on U.S. firms in manufacturing the 64K dynamic random access memory chip because they used an older, conventional technology while the U.S. companies were trying to get the bugs out of a newer one.

46 These figures are from VLSI Research Inc., and are for all semiconductor production, including intra-company captive production as well as merchant production for the open market. Figures from Dataquest are for merchant semiconductor production only; they show U.S. producers holding 37 percent of the world market in 1988 (down from 61 percent in 1980), and Japanese producers holding 50 percent; see National Advisory Committee on Semiconductors, *A Strategic Industry at Risk*, a report to the President and the Congress (Arlington, VA: The Committee, 1989).

Figure 5-5—World Semiconductor Sales



SOURCE: VLSI Research, Inc.

rest. Most U.S. companies that sell on the market are smaller, less stable, and less integrated. Some make virtually nothing but chips. Although there are large integrated U.S. companies making chips—IBM, AT&T, the Delco division of GM—they typically use most of the chips they make and buy more besides.

One explanation for the explosive success of the Japanese is the structure of their industry. It has been strongly argued that the vertical integration, large size, and product diversity of Japanese firms give them an advantage of staying power that is almost unbeatable---even if the U.S. industry succeeds in its strenuous efforts to catch up to the Japanese in manufacturing excellence.[47] Moreover, the big integrated firms can use their most advanced chips to improve their own end products (computers, work stations, robots) well before they sell the chips on the open market to competitors.

It is true that Japanese firms are using their structural features to advantage (American firms with much the same features have not been so successful, however). Possibly other arrangements—close collaborative relations between suppliers and customer firms, say--could give U.S. companies many of the same benefits that the integrated Japanese firms enjoy. These arrangements would not, however, provide the kind of financial strength that helped the Japanese firms weather the steep semiconductor recession in 1985-86. (Volatile demand, independent of the business cycle in the economy as a whole, is typical of the semiconductor industry, although the 1985-86 downturn was deeper than usual.) But it is well to remember that the Japanese industry was not always so well-heeled as it is today. One must look to other factors to explain Japanese staying power before the plush era of the later 1980s. Government support, financial and otherwise, had much to do with it. So did the well-known ability of Japanese managers to take a long-run strategic view, rather than going for short-term profits.

The supposed advantages of integration and large size are most relevant to the semiconductor industry. (Lesser integration is often proposed as a remedy for other industries--eg., the supplier group system as easier to manage and more conducive to innovation than GM-style integration in autos; mini-mills as more flexible, responsive, and efficient than the integrated behemoths of the steel industry.) But the semiconductor industry is well worth consideration on its own, for it is at the heart of technological advance in every sector of the economy, from autos to computers to banks to defense.

Links to Markets, Financial Stability

All the leading Japanese semiconductor producers belong to big, vertically integrated firms. All sell chips on the open market, but some 50 to 70 percent of the chips they make are used internally or sold to an affiliated firm in their industry group.[48] Facing competition in the open market probably strengthens their performance, and having a large, reliable demand lessens the risk in investing the $300 million or more that building a state-of-the-art semiconductor plant now requires. In addition, a big, diversified company can see its semiconductor division through periodic downturns in demand, as in 1985-86, when Japanese producers are estimated to have lost $3 to $5 billion, and U.S. producers some $2 billion in memory chips. While the demand for computers, and consequently for memory chips, plunged, the Japanese companies' sales of other electronics products such as VCRs and compact disk

[47] For an example, see Michael L. Dertouzos, Richard K. Lester, Robert M. Solow and the MIT Commission on Industrial Productivity, *Made in America: Regaining the Productive Edge* (Cambridge, MA: The MIT Press, 1989), pp. 248-262.

[48] Michael G. Borrus, *Competing for Control: America's Stake in Microelectronics* (Cambridge, MA: Ballinger Publishing CO., 1988), P. 111, table 54.

players held up. The top six Japanese semiconductor producers (NEC, Hitachi, Toshiba, Fujitsu, Matsushita, and Mitsubishi) are divisions of integrated electronics firms that had sales of $10 to $23 billion in 1987. Semiconductors accounted for only 8 to 17 percent of their sales.

The top U.S. firms are much more various. Of eight leaders (companies ranking in the top 20 for world market share), two, IBM and Hewlett-Packard, produce chips almost solely for their own use. The rest range from about 20 percent outside sales (AT&T, which recently began to push external sales) to more than 90 percent. The leading U.S. merchant producers—those that sell on the open market-range in size from medium to modest compared to the Japanese electronic giants. The two largest are Motorola and Texas Instruments, both diversified electronics firms of medium size, with total company sales of around $5 to $7 billion in 1988. Much of their chip production is for their own use but they are also big producers for the market; semiconductors count for one-third or more of their sales. The other leading merchant firms (Intel, Advanced Micro Devices, National Semiconductor, Fairchild) are primarily in the chip business.[49] They sell mostly to outside firms, and therefore lack the assurance of a large internal market. They are considerably smaller than Motorola and Texas Instruments (not to mention the Japanese electronics companies), with sales that run from about $1 billion to $2.5 billion. (IBM is primarily a computer and electronic systems company but is also the biggest of all the semiconductor producers; its total sales in all product lines were $54 billion in 1988.)

Large size, diversity of product, and vertical integration can have their down sides too; for example, bureaucratic clumsiness and top management that does not understand the semiconductor business. Indeed, in the United States, the moderate size and flexibility of entrepreneurial semiconductor firms have been hailed as the source of creativity and innovation. And, in this country at least, some highly diversified and vertically integrated companies have tried the semiconductor business with only limited success (e.g., RCA and Westinghouse). AT&T, a very large company ($34 billion in sales in 1988) with a big internal market in telecommunications equipment, recently abandoned production of DRAMs.

It seems that large size and a high degree of integration are no guarantee of success in the semiconductor business. But are they necessary even if not sufficient? (The question applies to major players in the game, not to small niche producers.) And if large, diverse, integrated firms have a built-in advantage, why hasn't the U.S. industry taken that direction? The answers to these questions are not simple or obvious. The U.S. industry developed a structure that was well-suited to an earlier period of the microelectronics business but does not fit as well with the requirements of a more mature industry. (However, other factors besides industry structure have also favored Japanese semiconductor producers as the industry matured; see the discussion below.)

The pioneering era of the business, from 1950s up to the mid- 1970s, was one of repeated technological upheaval as products were rapidly introduced and then just as quickly superseded. The germanium transistor gave way to the silicon transistor; integrated circuits ousted the single transistor for most uses; MOS (metal oxide semiconductors) succeeded and largely replaced bipolar logic in highly integrated systems, as in the memory chips used in computers. This environment of turmoil and frequent change was favorable to startups of new, creative companies bankrolled by venture capital. High turnover—20 percent a year on average, including top ranking professionals and managers as well as production workers—has been the hallmark of Silicon Valley since its early days. Engineers and scientists repeatedly peeled off and spawned new generations of highly innovative, but often short-lived, firms with a strong focus on new products. Along with the new products came substantial changes in the manufacturing process.

In about the last dozen years, microelectronics has settled down. Important changes are still occurring, but they have become more incremental than revolutionary. The 1-megabit memory chip of the late 1980s is a fairly direct descendant of the 16-kilobit chip of 10 or 12 years earlier. It is made by essentially the same methods. But making chips with ever finer lines and greater density requires ever

[49] Fairchild Semiconductor Corp., formerly a subsidiary of the international conglomerate Schlumberger, Ltd., was recently acquired by National Semiconductor Corp. The sales figures cited here are from the 1989 edition of *Standard and Poor's Register of Corporations, Directors and Executives* (New York, NY: McGraw-Hill, 1989); they do not reflect the acquisition.

more complex machinery, more exacting conditions of manufacture, and greater capital investments. The $300 million or more that it takes to build and equip a semiconductor plant for memory chips today compares with an entry cost of $5 million or so in the early 1970s.

Three characteristics of Japanese industry, apart from structure, are advantageous in the present stage of the microelectronics business. One is the demonstrated excellence of the Japanese in manufacturing. As an industry matures and incremental improvement takes the place of radical innovation, what counts most is the ability to shorten the cycle of product development, to get the latest version of a product to market quickly, and to make the product to high standards of quality and reliability, at a competitive price. This is just what the Japanese did, beginning with the sudden conquest of half the U.S. market for 16K random access memory chips in 1980 and continuing with its successors, up through the l-megabit chip. Many well-known aspects of the Japanese system of manufacturing--collaboration between design and manufacturing engineers, scrupulous attention to every detail of manufacturing, the team system for shop floor workers and their close involvement in quality and productivity, close cooperative links with suppliers, and a long-term view on the part of managers-contributed to this outcome.

Another factor is the relatively low cost of capital in Japan and the favorable conditions banks and shareholders have long offered to major manufacturers—a factor that grows in importance as capital costs rise.[50] Related to this is the long-term view characteristic of Japanese managers. The lower capital costs are, the longer a company can reasonably wait for payoffs on its investment. Also, the lifetime employment offered by large Japanese companies, and the fact that employees typically stay with one company for their entire careers, contributes to a strategy of counting on market growth for prosperity, rather than taking instant profits. The highly unstable attachment to companies in Silicon Valley pushes in the opposite direction. Still another factor, not discussed here but to be considered in a following report, is the contribution of the Japanese Government's industrial and trade policies to the success of industries considered critical to the nation's economic future—government support of R&D and assurance of a plentiful supply of low-cost capital, combined with export promotion, tight restriction of foreign investment, and protection of the domestic market.

With this perspective, it may be seen that the more-or-less assured markets for semiconductors that a vertically integrated electronics firm can offer, the stability furnished by product diversity, and the greater power to make capital investments that comes with large size are great assets for the big Japanese electronics companies, but are not by themselves *the* decisive assets. A recent example from Japan underscores the point that vertical integration is not prerequisite to success. NMB Technologies Inc. is a subsidiary of a prosperous but not very large Japanese company, Minebea, which has a $1.5 billion yearly business in precision ball bearings. Entering the semiconductor business in 1983, NMB invested $250 million in a world-class fabrication plant, and started producing superfast DRAMs in volume in 1985. Despite the world recession in chips, NMB hung on, and was ready with suitable fast memory chips when Intel and Motorola introduced their 32-bit microprocessors for top-grade personal computers in 1986. Granted, fast DRAMs are something of a niche market; yet the investment required to get into the business was far from trivial. NMB may later fall victim to a bigger company deciding to compete in fast DRAMs, but in 1989, only 4 years after starting production, it had 90 percent of the world market in fast DRAMs, and expected to double its 1988 sales of $250 million.[51]

For stand-alone semiconductor firms there maybe alternatives to the internal markets that integrated companies provide. Long-term, stable relationships between chipmakers and chip users (i.e., builders of computers, work stations, telecommunications equipment, industrial machinery, automobiles, consumer electronic goods) might offer similar benefits. An example is the close ties between IBM and Intel, which makes a microprocessor for IBM computers. NMB owed much of its success to cultivation of close links with users such as Compaq Computer

[50] The great prosperity of the Japanese electronics Companies in the late 1980s (and indeed of the entire Japanese economy) has reduced the importance of bank loans and outside equity holders; many of these companies today are capable of meeting most of their own financial needs. See ch. 3 for discussion of this issue.

[51] Larry Wailer, "How NMB Took Over the Fast-DRAM Market," *Electronics*, November 1988.

Corp. (its biggest customer) and Lockheed Aircraft Corp.

Compared with their performance in manufacturing standard commodity memory chips, U.S. producers do better in the kind of chips where individual product design and attention to customers' needs are paramount and price is secondary (e.g., microprocessors and application-specific integrated circuits, or ASICs). However, two can play at this game. The top three firms in ASIC sales are Japanese. Not only do they sell ASICs at home, they operate design centers in Boston and Silicon Valley, send the designs back to Japan by satellite communication, and deliver the custom (or semi-custom) chips by air. The greatest remaining U.S. advantage is in microprocessors, where the creative talent of designers (a U.S. strong point) is of paramount importance; also, users of microprocessors tend to form long-term ties with producers because they invest in software that fits their particular microprocessor and its progeny.

For mass-production chips, however, investments in semiconductor plants have become so huge and the sales needed to justify them so large that it may be a good deal harder for an independent. undiversified company to prosper now than it was in the past. The plenitude of capital that the large, integrated electronics companies of Japan possess may be a critical asset. It is sobering to reflect that among U.S. firms, only IBM, Texas Instruments and the much smaller Micron Technology, Inc. stuck with DRAM production through the late 1980s, and most of Texas Instrument's production was in its Japanese facilities. (Motorola was getting back into production of DRAMs in 1989, after making an agreement with Toshiba to swap a license to produce Motorola's microprocessor in return for access to Toshiba's l-megabit DRAM technology.) As recently as 1980, there were 11 U.S. companies making DRAMs. This mass-production chip is essential to computers, telecommunications, and many other kinds of equipment, and has been a favorite technology driver for the industry .[52]

The purpose of Sematech, the government-industry R&D consortium in semiconductor manufacturing technology, is to help U.S. producers regain competitiveness in DRAMs and other memory chips. Sematech is a novel venture for the United States; not only has it put together industry and government funding on a large scale, it is forming stronger vertical links than have existed before in the U.S. microelectronics industry and is creating unprecedented horizontal links between competitors. Sematech is confined to R&D, stopping short of manufacture. A more radical approach was the proposal by several U.S. computer and semiconductor companies, announced in June 1989, to form a consortium and produce DRAMs commercially. The project failed to attract enough computer firms as participants, however, and was abandoned in January 1990.[53]

Links With Consumer Electronics

Another question about linkage in microelectronics is whether the loss of the U.S. consumer electronics industry has deprived American chipmakers of an essential market. For Japanese chipmakers it is a huge market, taking 40 percent of production; this compares to 7 percent for U.S. producers. The decline in U.S. producers' share of the world semiconductor market does track to some extent the decline in U.S. market share of consumer electronic goods; in other words, other purchasers have not fully made up for the lack of sales to makers of television and radio sets, VCRs, compact disk players, and the like.

Up to this point, the loss of sales in consumer electronics has hurt U.S. chipmakers more financially than technologically. This is because most of the chips used in consumer electronics differ basically from those used in computers, telecommunications equipment, and other high-technology products. Analog devices, which receive an analog signal

[52]Technology drivers are chips whose manufacture provides learning experience that can then be applied to other kinds of chips or later generations of the same chip. DRAMs are good technology drivers because: 1) they are produced in large enough volume to supply data quickly for statistical analyses; 2) they are high-density integrated circuits that push the limits of current lithography technology; 3) they have a simple repetitive design, which makes it easy to test them for design or production defects; and 4) the manufacturing equipment and process technology required for DRAM production is similar to that required for other chips.

[53]Charter members were three computer manufacturers (IBM, Digital Equipment Corp., and Hewlett-Packard) and four chipmakers (Intel, Advanced Micro Devices, Nationat Semiconductor, and LSI Logic). Both Apple Computer and Sun Microsystems decided not to participate, A spokeswoman for Sun cited its "global purchasing strategy" and "existing long-term agreements with other chipmakers as reason for refusal to join. ''Electronics Newsletter," *Electronics,* December 1989, p. 17.

and amplify it, are much used in consumer electronics. Computers and the like use digital chips. At one time (until the late 1970s) this divergence was something of a handicap to Japanese semiconductor producers. While they excelled in manufacture of analog devices for their booming consumer electronics business, much of that experience did not carry over into the production of large-scale integrated circuits based on digital electronics (with the VLSI project, Japanese manufacturers got over this technological hump).[54]

Today, consumer electronic goods are changing course toward much greater consumption of digital chips. Compact disk players already use them. New generations of television sets and related products will use far more. There are about 160 million television sets in the United States, which suggests that the potential market for digital chips for television alone could be large. Semiconductor producers who fail to get into this market could find themselves at a disadvantage-but not just in the TV market. More importantly, they could fall behind in the know-how required for making successive generations of computers and their applications. This is because the core technologies for consumer electronics on the one hand, and computers plus many other advanced business products, on the other hand, are converging.

All digital chips are in the same family—i.e., they are made with similar kinds of equipment and manufacturing processes. Anyone who can meet the exacting requirements for mass-producing digital chips for consumer electronics items—high volume, low cost, high reliability—gains valuable learning experience in making similar kinds of chips, well and cheaply, for computers and other business products. The same goes for other components that computers, telecommunications, and other business products have in common with consumer electronics items. Moreover, advanced television could be the application where certain leading edge technologies—e.g., advanced displays and the new manufacturing technologies needed to make them—will be needed first.[55]

The Japanese are making rapid progress toward commercializing high definition television (HDTV), and some companies are already poised to sell an advanced version of conventional television that has much improved definition. The United States is far behind. Zenith, the last remaining U.S.-owned producer of television sets, has not yet brought to market an improved definition TV (IDTV), and is a late and uncertain entrant in the HDTV race. (Foreign-owned firms with production facilities in the United States are pursuing advanced television systems, however. The Dutch-owned Philips has an IDTV on the market, and the French-owned Thomson Consumer Electronics has demonstrated an extended definition TV.) After the Defense Advanced Research Projects Agency (DANA) set aside $30 million to encourage U.S. producers to make HDTV's, Zenith proposed to collaborate with AT&T on such a venture; a number of computer and work station manufacturers are also interested. But so far, HDTV activity by U.S.-owned companies is confined to research and the earlier states of development, with commercial production still years away.

Technology Links

Another way that a vertically integrated company may get ahead of the competition is to develop its own advanced technology, and keep it for itself. For example, both Hitachi and IBM are said to have developed some superior production equipment that they never sold or licensed to anyone else.

A similar kind of technology link is part of the rising threat from Japan to the U.S. lead in supercomputers, the fastest and most powerful of computing machines. Three Japanese electronics companies (NEC, Hitachi, Fujitsu) are narrowing the U.S. lead. These large, integrated companies make their own high-speed components. Currently the world leader, and the only U.S. company making supercomputers, is the comparatively small, stand-alone firm Cray

[54]U.S. Congress, Office of Technology Assessment, *International Competitiveness in Electronics,* OTA-ISC-200 (Springfield, VA: National Technical Information Service, November 1983), pp. 196-198.

[55]For details, see the section on advanced television in ch. 2, and OTA's forthcoming report, *The Big picture.*

Research Inc.[56] Cray does not make the high-speed components needed for supercomputers, and they are hard to get from other U.S. companies. This is one of the main reasons why the U.S. lead is evaporating, according to a report by a panel of computer science experts to the Institute of Electrical and Electronics Engineers, Inc. (IEEE) .57 The report said:

> The highest performance memory and bipolar logic components useful for supercomputers . . . are available only from Japan. The managements of Cray and ETA have been quoted in the press at various times as stating that these Japanese components are "not yet available for export' from Japan to Cray or ETA as devices-but they are available to end users in the Japanese supercomputer systems. Those systems are definitely available for export.

A senior NEC manager, Akihiro Iwaya, underscored the point in an interview with *The New York Times.* He said: "We have our own chip divisions. They can custom-make the high-speed chips we need. Cray can't. They have to buy them from Japan. '[58]

Officially, Cray managers have no complaint about their Japanese suppliers. And indeed it is unlikely that Japanese producers would cut off supplies to Cray, partly because that would cause political troubles for Japan, and partly because sale of the chips is highly profitable. What is more likely is delay in providing the latest and best chips to Cray. According to one informed observer, both the Japanese firms are delaying up to a year in providing their latest chips to their American competitor.

Cray is under challenge from larger, more integrated companies in another way as well. Cray gained its leading position in supercomputers by its excellence in what the industry calls packaging, that is contriving to arrange chips in close quarters for speedy operation, while draining away the heat they generate. While Cray still has the reputation for outstanding engineering, it is facing very tough competition from bigger companies that make a full line of computers, from mainframes down through personal computers. Such companies can afford to devote a lot of engineering talent to solving packaging problems, since the results can eventually be applied not just to supercomputers but to the full line, and the costs recovered from this broad range of products. The same consideration may apply to other kinds of R&D spending as well, Not all of this particular advantage resides in Japan, however. IBM too makes a range of computers, and is supporting the efforts of a former Cray engineer (Steven Chen) to build a new improved supercomputer.

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[56]The still smaller ETA, a subsidiary of Control Data Corp., dropped out of supercomputer production in April 1989. Also, in May 1989, Cray Research spun off anew company, Cray Computer, to be run by Seymour Cray, the founder and chief designer of Cray Research. Funded by Cray Research with $100 million over 2 years, the new company was setup to pioneer a promising but risky technology based on gallium arsenide chips. Reportedly, the reason for the move was to free Seymour Cray from the short-term pressures of Wall Street. (Alan Kane and Louise Kehoe, 'Challenge to the U.S. Brains Trust," *Financial Times,* May 18, 1989.)

[57]IEEE/USAB Committee on Communications and Information Policy, "U.S. Supercomputer Vulnerability, ''report to the Institute of Electrical and Electronics Engineers, Inc., prepared by the Scientific Supercomputer Subcommittee, Committee on Communications and Information Policy, United States Activities Board (Washington, DC, August 1988).

[58]David E. Sanger, ''A High-Tech Lead in Danger, ' *The New York Times,* Dec. 18, 1988, sec. 3, p. 1.