grams for people first, we expect to multiply the productivity improvements that are gained through technology and capital investments. With participative management, for instance, employees welcome advanced technology because they feel in charge of it. Only when these programs are in place will we emerge from the showcase and token automation phase that manufacturing is presently in.

Today, scientific work in the application of computers to factory automation is in the embryonic stage. We are on the verge of seeing the cost of NC, CNC, and robotics become low enough for these systems to be economically justifiable for many more applications. The cost will continue to decline as application problems are resolved and the computer becomes an understood and respected partner in the manufacturing environment. When this happens, our nation's productivity will be greatly enhanced.

References and Notes

1. "The reindustrialization of America," *Business Week*, 30 June 1980, p. 9.
2. "Information systems planning guide," unpublished internal manuscript, Westinghouse Electric Corporation.
3. J. K. Krouse, "CAD/CAM—bridging the gap from design to production," *IEEE Trans. Prof. Commun.* **PC-33**, 191 (1980).
4. "ICAM program prospectus, manufacturing technology," U.S. Air Force, September 1979.
5. "A report on robotics in Japan," *Robotics Today* **3**, 26 (Fall 1981).
6. Delphi Study, Society of Manufacturing Engineers, Dearborn, Mich., 1981.
7. A. K. Bejczy, *Science* **208**, 1327 (1980).
8. R. Sugarman, *IEEE Spectrum* **17**, 53 (September 1980).

Japan–U.S. Competition: Semiconductors Are the Key

John Walsh

Summary. Japan appears to have achieved a breakthrough with its success in selling the 16K random access memory chip. The rivalry between Japan and the United States over integrated circuits could make the 1980's crucial years in the contest for the lead in the world electronics trade.

The United States continues to dominate world trade in electronics. In 1980, the U.S. balance of trade surplus in electronics was $6.8 billion on exports of $20.1 billion and imports of $13.3 billion—up 38 percent from the previous year (Table 1) (*1*). In bilateral trade with Japan in 1980, however, the United States imported nearly $4 billion more in electronics than it exported (Table 2). And trends in Japan–U.S. trade have given rise in this country to concern that the long-held American lead in the high-technology sector of electronics is eroding. The perception is growing here that what is at stake is not simply first place in a rapidly expanding international market, but world primacy in technology.

What prompts this view is the phenomenon, described in this issue, of the widening application of microelectronics to manufacturing and communications and to the infusion of information technology into virtually every aspect of commerce and technology. In this decade, a decisive contest is foreseen between Japanese and American industry for superiority in integrated circuits, the key constituent of the smart machines of tomorrow.

Governments of industrial countries are increasingly acting on the view that maintenance of a viable electronics industry is essential to economic well-being and military security. Several Western European countries are following the example of Japan in fashioning national policies designed to assist their electronics industries to achieve competitive positions in world markets.

The rivalry in electronics is occurring against a background of inflation, recession, and unemployment in Western industrial nations. In the United States, microelectronics is seen as offering an effective counter to declining technological innovation and industrial productivity. At the same time, however, there is apprehension that microelectronics-driven automation will cause greater loss of jobs and social dislocation. For all these reasons, protectionist sentiment toward foreign trade is mounting in the United States and Western Europe.

Protectionist feeling in this country is directed most strongly against Japan; the United States faces an expected trade deficit of $28 billion overall for 1981 (*2*) and a deficit of $15 billion in trade with Japan. Resentment is sharpened by a general perception that Japan has used tariff and nontariff barriers to shelter its own industry.

While trade relations are receiving considerable notice, the broader dimensions of the Japanese challenge are attracting attention in industry and government; comparisons are increasingly being made of the structure of industry, financial systems, and social organization in the two countries.

Supremacy in microelectronics is equated with the holding of a commanding position in the sales of semiconductors and computers. The United States retains a world lead in both categories. The Japanese, however, have recently won a round in the semiconductor competition that some informed observers see as presaging the kind of success they scored earlier with textiles, footwear, steel, shipbuilding, consumer electronics, and, most recently and conspicuously, automobiles.

Breakthrough for Japan

The Japanese surge came with sales of the 16K random access memory (RAM) chip, widely used in multiples for computer memories. The 16K RAM was introduced by American companies in the mid-1970's, but the supply of American-made 16K chips fell short of demand. Opinion is somewhat divided on why the shortfall occurred. Some observers attribute it to an underestimate of demand. Others note that unexpected difficulties in production were encountered. A more general view, however, is that, in the recession that followed the oil crisis of 1974, U.S. industry failed to

The author is a member of the News and Comment staff of *Science*.

0036-8075/82/0212-0825$01.00/0

Table 1. U.S. imports and exports of electronic products and balance of trade for 1978 and 1980 (millions of dollars) (*1*).

Product	1978			1980		
	Imports	Exports	Balance of trade	Imports	Exports	Balance of trade
Consumer electronics	4,677	602	−4,075	4,501	814	−3,687
Communications products	780	1,543	763	1,036	1,872	836
Industrial products	1,450	7,476	6,026	1,935	11,692	9,757
Electron tubes	183	256	73	258	367	109
Electronic parts	1,569	1,792	223	2,355	2,654	299
Solid-state products	1,680	1,528	−152	2,971	2,748	−223
Other	368	200	−168	258	44	−214
Total	10,707	13,397	2,690	13,314	20,191	6,877

make the necessary investment in new production facilities. Japanese manufacturers were able to market a chip competitive with American designs, in part because of a collaborative project on very large scale integration, backed by the Japanese government, in which major semiconductor producers participated. Within 2 years, the Japanese gained an estimated 40 percent of the market for the 16K chip.

A report on competitive factors affecting world trade in integrated circuits by the U.S. International Trade Commission in 1979 noted that U.S. industry was "losing world market share as Japan and the European countries, through technology transfer and research, expand their production bases and become more efficient as a result of production experience and economies of scale. Based on investigation findings, the Japanese industry appears to be able to produce a given level of output for a lower input of capital and labor than the U.S. industry" (*3*).

Not only did American companies suffer a loss of market share, but they were stung by remarks about the superior quality of Japanese 16K chips. In March 1980, Richard W. Anderson, head of the computer systems division of Hewlett-Packard, made a widely noted comment that Japanese-made chips used in Hewlett-Packard products were lower in price and better in quality than American equivalents. Hewlett-Packard, a major computer manufacturer and an important customer for integrated circuits, was one of the American manufacturers that bought large numbers of 16K chips from the Japanese. Anderson quoted company data indicating that chips from Japan showed fewer failures both in factory testing and in customers' hands. In a rating of chips from three Japanese manufacturers and three American manufacturers, all of the Japanese firms scored over 86 points whereas the American companies' products scored 85, 67, and 48 (*4*).

Interviews with U.S. industry and trade association executives revealed a view that the Japanese success with the 16K RAM illustrates the ability of the Japanese to identify a promising market opportunity and to exploit it successfully. They also suggest that the incident illustrates Japanese trade tactics. In 1978, the U.S. Semiconductor Industry Association complained to the U.S. International Trade Commission that the Japanese were charging prices for 16K chips in this country that were 30 percent lower than the prices charged in Japan; they claimed that Japanese penetration of the U.S. market was being subsidized by Japanese customers. Prices were subsequently adjusted upward, but U.S. executives contend that even the new prices allowed little profit and were intended by the Japanese to enable them to establish themselves in the market. Many U.S. manufacturers are said to have been influenced to shift away from producing 16K RAM's by the low prices. In 1979, the United States ran its first trade deficit with Japan in integrated circuits. The $3.7-million deficit was expected to exceed $240 million in 1980 (*5*).

What inferences can be drawn from Japanese breakthrough with the 16K RAM? Are the Japanese likely to have similar success with the next generation chip, the 64K? The influential electronics industry analyst Benjamin M. Rosen made the following somber assessment in the September issue of the newsletter he publishes (*6*). "The grim fact faced by U.S. semiconductor manufactuers is that they are losing market share to their Japanese competitors in dynamic RAM memory devices, that this share won't be regained, and that the implications are potentially serious."

Rosen goes on to say, "Today, as the 64K chips ramp up into volume production, six Japanese manufacturers [Hitachi, Fujitsu, NEC (Nippon Electric Company), Mitsubishi, Oki, and Toshiba] and two American manufacturers (Texas Instruments and Motorola) share the market. Their shares, however, are not equal. The Japanese vendors in aggregate are probably shipping over 80 percent of the parts." Rosen and others expect Japanese hegemony to spread to other sectors of the memory market.

The outlook for the U.S. semiconductor industry is heavily affected by the peculiar economics of the industry. As in competitive industries generally, prices for a particular type of integrated circuit decline as production costs go down. This is defined as the working of the experience curve or learning curve. In the semiconductor industry, the rapid rate of technological change and the highly competitive world market create conditions under which a few manufacturers can establish a commanding market position.

The Experience Curve

Although design competence is obviously important, success on the experience curve depends on mastery of the production of wafers, the silicon disks on which multiple chips are fabricated. "Yield," or the percentage of good units, as a 1980 Charles River Associates report (*7*) puts it, "is the fundamental determinant of costs and profits."

Semiconductor manufacturers tend to set prices according to their estimates of where they will have advanced on the learning curve at some future time, rather than on current costs. Manufacturers entering the market late, therefore, find it difficult to compete.

The semiconductor industry's growth has been powered by the very rapid increase in the logic or memory capacity of the individual chips, called "functional density." As the complexity of the chips increased, so too did costs of fabrication facilities. The cost of integrated circuit production lines is estimated to have tripled between 1975 and 1980. Today, such heavy investment is required that only a few manufacturers will be able to carry a new design through to production.

U.S. manufactuers have depended on capturing a share of the market for one device to enable them to invest in development of the next. Now, not only are U.S. semiconductor manufacturers' revenues down because of recession conditions and low returns from the 16K chip, but investment funds are at a premium

because of high interest rates and, at least until recently, the scarcity of venture capital.

With respect to the next generation of memory chips, the Japanese are reported to be making up to 70 percent of shipments of 64K chips currently. Hitachi and Fujitsu have been the two leading shippers, with Motorola in third place. The 64K chip, however, has not swept the market. Manufacturing difficulties have kept yields low, and low prices have made the 16K chip more attractive to customers than the 64K chip. In November, however, Nippon Electric Company, the leading producer of 64K RAM chips announced that it was raising production of the 64K to 1 million a month from the present level of 100,000 to 200,000 (*8*). Hitachi and Fujitsu also indicated plans for mass production of the 64K chip. In the offing is competition over the next fourfold increase in capacity, the 256K chip. The Japanese have already staked a claim by announcing the details of a 256K chip they have under development.

The question of whether the United States will remain competitive with Japan in high technology is increasingly cast in terms of comparisons between the two widely differing industrial systems. Japanese attitudes and policy have been shaped by the sense that as a densely populated island nation with limited natural resources Japan was compelled to excel as a trading nation. After World War II, protection of Japanese industry was sanctioned by laws designed to encourage reconstruction of the Japanese economy. In the postwar period, a strategy for success in world trade was refined through a partnership involving government, industry, and labor. The strategy required targeting of promising products for world markets and the production of high-quality goods at economic costs by Japan's well-educated, skilled, and disciplined work force.

By the early 1970's, the Japanese had attained many of their economic goals but were encountering serious environmental damage from heavy manufacturing activities. Perceiving the promise of burgeoning information technology, the Japanese adopted a national policy of emphasizing "knowledge-intensive" industry. In line with this decision, semiconductor and computer industries were singled out for special treatment by the government.

The results after a decade, as seen from the viewpoint of the U.S. semiconductor industry, were summarized by George Scalise, vice president of Advanced Micro Devices, at a congressional hearing on Japan–U.S. competition (*9*).

Table 2. Comparison of exports of U.S. electronic equipment to Japan and Japanese electronic equipment to the United States (millions of dollars) (*16*).

Product	1975		1980	
	U.S.	Japan	U.S.	Japan
Telephone and telegraph equipment	5.6	25.6	6.6	163.3
Electronic systems and equipment (commercial, military, and industrial)	52.8	111.2	76.9	438.6
Electronic components	109.1	161.2	238.2	830.0
Consumer electronics	22.1	1251.5	61.6	2337.1
Electronic computing equipment	189.3	32.3	607.3	189.3
Calculating and accounting machines	9.4	180.1	22.2	373.3
Typewriters and office machines	4.4	100.1	25.5	256.6
Photocopying machines	4.6	70.2	17.7	424.0
Total	397.2	1903.1	1056.0	5012.2
Trade balance	−1505.9		−3956.2	

Through the 1960's, Scalise said, tight restrictions in the semiconductor and computer areas had enabled U.S. companies to export only sporadically into Japan.

Early in the 1970's, Japan began liberalizing restrictions on imports of, and investment in, computer equipment. Computer duties began to be reduced. Then in 1971, Japan took the significant step which was to lead to their industry's challenge to U.S. leadership in the world semiconductor and computer markets. Realizing the vast potential in many industries of this knowledge-intensive industry, the Japanese government sponsored the promotion of computers through selected Japanese companies which were to develop high-performance computers and peripheral equipment (and later software) to support Japan's entry into worldwide competition. Direct subsidies in the order of $200 million were granted for this effort, but more significant were the cooperative laboratories, carefully orchestrated by the Ministry of International Trade (MITI) and the quasi-government monopoly, Nippon Telegraph and Telephone (NTT).

Significant tax incentives were afforded integrated ciruit and computer operations under the government development program:

- In addition to normal depreciation, facilities and equipment were allowed to be depreciated in the first year by an amount equal to one-third of the initial book value.
- The Government also provided tax incentives to Japanese end-users to promote the purchase of computers.
- Research and development tax credits were furnished participating firms for incremental expenditures over a base year.

An important element of this initial government-industry research program was the Very Large Scale Integration (VLSI) program whose mission was to develop processes to manufacture the most advanced integrated circuits by the mid-to-late 1970's. As part of this effort, the latest American process equipment was purchased for detailed evaluation and refinement. The VLSI program terminated in early 1980, having achieved a very significant result: through systematic adaptation of American state-of-the-art products and processes, the Japanese companies closed the technology gap with the American companies for the manufacture of the 16K RAM, a high volume memory chip used in computer systems.

Government involvement is not, however, portrayed by Scalise as the key element in the Japanese challenge. He noted that the members of the Semiconductor Industry Association concluded, after intensive research, that the most serious aspect of the commercial competition from Japanese companies arose from the structural differences between the economic environments in the United States and Japan. "Indeed, these structural differences constitute the greatest threat to the long-term viability of the U.S. industry."

Although the U.S. semiconductor industry is regarded as a model of innovative vitality in this country, its structure is believed to put it at a disadvantage in the competition with the Japanese. In Japan, semiconductor production typically is carried out by divisions of large electrical manufacturing companies such as NEC and Hitachi. These units make integrated circuits for other divisions of their own companies and also sell them to other manufacturers. In the United States, independent semiconductor manufacturers like Fairchild, Texas Instruments, and (later) Intel preempted the market from major electrical manufacturers like General Electric and Westinghouse and concentrated on selling components to manufacturers of end products. The manufacture of the more profitable electronics end products has given the diversified Japanese companies an edge over many U.S. companies.

For the capital-intensive semiconductor industry, differences in capital formation practices in the two countries also appear to favor the Japanese. The world demand for integrated circuits has been growing at an average rate of 25 percent a year. Companies must expand at that rate to maintain their market share, and the rising cost of fabrication facilities heightens the requirements for investment funds.

In Japan, large multiproduct compa-

nies like NEC, Hitachi, Fujitsu, and Toshiba generate investment capital internally from profits or obtain loans from banks that are tied closely to parent companies. These banks, which maintain close, long-term relations with particular companies, are firmly controlled by the government.

American companies typically finance expansion out of earnings and the issue of stock. The portion of investment capital borrowed from banks is less important. The venture capital market that fueled expansion in the early period of the U.S. semiconductor industry boom has until recently been supine, and recession and high interest rates have limited other sources of investment funds. Japanese companies pay interest rates that are low compared with that paid by their U.S. counterparts and, therefore, despite levels of indebtedness higher than is customary in the United States, they are better able to manage expansion.

The market strategy of Japanese companies also works to their advantage in electronics. American companies, traditionally dependent on stock issue for capital, have been concerned with short-term profits, in part because management is answerable to stockholders concerned with profitability. Japanese companies, because they are export oriented, put greater emphasis on expanding market share than on immediate profits. Japanese managers also appear to have greater freedom in using resources to pay for research and development and for personnel training, as well as for investment in plant.

Dimensions of Difference

Differences in culture and social organization between Japan and the United States are increasingly seen as important. Japanese efficiency is attributed, in part, to Japan's homogeneous society and its workers' acceptance of a group identity in contrast to the individualistic values asserted in the United States. Company loyalty in Japan is reinforced by practices such as lifetime employment and grading of pay according to seniority. Pay differentials between top executives and workers in Japan are substantially smaller than they are in the United States and Europe. Workers in Japan by and large appear to identify their own interests more closely with those of their company and the nation than do their counterparts in the West.

An argument made by Ezra F. Vogel of Harvard and others is that the Japanese have been more successful than Western nations in dealing with economic change in postindustrial society (*10*). In particular, the Japanese have found better ways to shift resources from mature industries in decline to growth industries and to retrain and redeploy displaced workers.

According to some observers, the difficulties U.S. firms have encountered in competing in Japanese markets are in substantial measure attributable to so-called nontariff barriers. Mirek J. Stevenson, chairman of the New York–based research and consulting firm Quantum Science Corporation, says "Trade barriers are not as big a factor as differences in customs in Japan." For example, says Stevenson, distribution channels in Japan are not suited to entry by U.S. firms. In Japan, dealers expect to be offered a complete range of products. Most U.S. manufacturers make a more limited range than do the large, diversified Japanese companies. On the other hand, U.S. distribution channels are well matched to Japanese exporters. For instance, Japanese photocopier manufacturers were able to establish themselves in the United States by selling small copiers through independent office equipment dealers and using that base to mount a more general challenge to Xerox and other major U.S. manufacturers.

Stevenson says that a key element in Japanese success in the United States and elsewhere is their great skill in assessing the potential market for particular products. United States companies, on the other hand, "have made a lot of mistakes," for instance in assuming that large television sets would prove attractive in small Japanese homes.

Despite the formidable Japanese challenge in semiconductors and computers, it is at least premature to assume that Japan will make a clean sweep of electronics. Industry patterns are changing in ways that some observers say will bolster U.S. ability to compete with Japanese companies. Takeovers of semiconductor companies by larger U.S. diversified companies are increasing; the purchase of Mostek Corp. for $345 million by United Technologies Corporation is an example (*11*). Stronger U.S. semiconductor companies are moving into greater vertical integration, adding electronics products for which profits are higher than they are for components. Intel, for example, is marketing a small computer based on its own successful microprocessor.

The internationalization of the semiconductor industry is proceeding rapidly. In this country, the French energy and electronics group Schlumberger bought Fairchild (*12*), and the British government invested heavily in research and production facilities in Colorado for its Inmos operations here. Japanese and American companies have undertaken a number of joint ventures both in the United States and in Japan. Japanese manufacturers are investing in production facilities here (*13*), in part to disarm criticism inspired by job losses in the United States. These trends, while significant, have not developed to the point where it is possible to predict how they will affect the fundamental terms of competition.

Sales of American semiconductor manufacturers are suffering from the recession, but industry executives say that their industry's ability to invest has been strengthened by the Reagan Administration tax law changes, particularly those that speed depreciation writeoffs and encourage research. Technologically, the United States retains the lead in several sectors of microelectronics, including microprocessors.

A Test for Japan

Industry observers also say that the next few years will test the Japanese capacity for innovation. The Japanese have excelled at adapting foreign technology and producing attractive, high-quality goods. Relatively few major technical advances have originated in Japan. Japan is increasing its spending on R & D, particularly on basic research, but that this will bring an early payoff in innovation is not assured.

In the quest for technological leadership, Japanese industry may also encounter some structural problems of its own. In making major market decisions, Japanese companies characteristically rely on a consensus process that involves all segments of management in the decision. This style has proved effective when Japan was exploiting technology originated abroad. It remains to be seen how this necessarily slower, consensual style will serve when Japan has to set the pace. Some doubts also remain about whether the Japanese can outdo the United States in providing software for the range of products expected to appear in coming years. The Japanese government targeted software development in one of its major collaborative efforts with industry in the 1970's and

has recently launched a new government-backed initiative (*14*). Japan has the manpower for the software effort, since it educates a larger number of engineers than the United States. But the dominant opinion here is that, for the time being at least, the United States is holding its own with software.

The immediate question is whether current friction between major trading partners will result in a round of protectionist action and reaction. In the past, such tensions have been contained within the framework of the General Agreement on Trade and Tariffs (GATT), and the issues were never politicized to the point where a trade war ignited. Trade between Japan and the United States under the GATT umbrella has been governed by a series of bilateral agreements and informal understandings. Both sides have made marked efforts to avoid confrontation.

In international trade negotiations, the Japanese, in general, have demonstrated a flexibility made possible by government-industry collaboration. In the past, when protectionist alarms have been raised against the Japanese, they have usually responded in ways that deflected damaging action, as they did recently by placing voluntary limits on the export of automobiles to the United States. In the middle 1970's when the Japanese achieved dominance in the U.S. color television market, Japanese companies avoided a full-scale confrontation, in part, by buying plants from U.S. companies and thus providing jobs for American workers.

An important safety valve has been the Trade Facilitation Committee, established jointly by the two governments, which has had some significant successes in settling complaints, usually made by American companies charging unfair trade practices. Another mechanism with more general aims was the Japan–United States Economic Relations Group, which included prominent private citizens from both countries. Established in 1979 by the late Prime Minister Ohira and President Carter, the group was asked to study long-term economic relations between the two countries and recommend ways to improve them. Known as the "wise men," the panel completed its work by mid-1981. In a supplemental report published in October 1981, the group urged that the Japanese continue the progress already made in opening its domestic market to foreign companies and also work to change the foreign preception of the Japanese market.

"The importance of these two tasks cannot be overstated. As a major beneficiary of an open world trading system, Japan benefits from continued efforts to preserve access to world markets. A collapse of this system would probably affect Japan more than the United States or the countries of Western Europe, although it would be a catastrophe for all three regions" (*15*).

The U.S. electronics industry has a major stake in open international markets and has maintained a free trade position. Although critical of Japanese unwillingness to open its markets to foreign imports, the U.S. industry stance in general is that if the federal government were to lift "disincentives" in tax, antitrust, and patent law and insist on genuine reciprocity in trade relations, American industry could compete with the Japanese. The Reagan Administration has made a start in dismantling such disincentives. But the key question in the microelectronics contest in the 1980's for the Japanese is whether they can surpass the United States in innovation; for the Americans it is whether they can overtake Japan in production efficiency.

References and Notes

1. "Electronic Market Data Book, 1981" (Electronic Industries Association, Washington, D.C., 1981), p. 100.
2. "Trade deficits spur the case for protection," *Business Week*, 2 November 1981, p. 48.
3. "Competitive Factors Influencing World Trade in Integrated Circuits" (U.S. International Trade Commission, Publication 1013, Washington, D.C., 1979), p. ix.
4. R. W. Anderson, "The Japanese success formula: quality equals the competitive edge," verbatim record of seminar, Electronic Industries Association of Japan, 25 March 1980, Washington, D.C.
5. Bureau of Industrial Economics, *1981 U.S. Industrial Outlook* (Department of Commerce, Washington, D.C., 1981), p. 313.
6. B. M. Rosen, *The Rosen Electronics Letter*, 30 September 1981.
7. "Innovation, Competition and Government Policy in the Semiconductor Industry" (Charles River Associates, Boston, Mass., 1980), pp. 2–35.
8. "Japan plans new semiconductors despite weak overseas market," *The Asian Wall Street Journal*, 23 November 1981, p. 5.
9. Statement by George Scalise before the Subcommittee on International Trade, Finance and Security Economics of the Joint Economic Committee, Washington, D.C., 9 July 1981.
10. E. F. Vogel, *Japan As Number One* (Harper & Row, New York, 1980).
11. "UTC's winning formula for exploiting Mostek," *Business Week*, 5 October 1981, p. 106.
12. "Fairchild: the kid whizzed," *The Economist*, 8 February 1981, p. 80.
13. "Tokyo, Calif." *The New York Times*, 1 November 1981, p. F-9.
14. "A big rush to rival the U.S. in software," *Business Week*, 5 October 1981, p. 50.
15. "Supplemental Report of the Japan–United States Economic Relations Group" (Japan–United States Economic Relations Group, Washington, D.C., 1981), p. 17.
16. "Trade gap with Japan widens," *Electronics*, 2 June 1981, p. 102.