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Back in the Chips

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Back in the Chips

Kenneth Bridges

If the study of history teaches us anything about the power of nations, it is the conclusion for which Paul Kennedy and his *Rise and Fall of the Great Powers* became famous—all national power, be it military power or political power, is derived from economic power. Today the single largest sector of the world's economy is the electronics industry. By the year 2000 it will be an annual \$2 trillion(!) industry. It already accounts for more jobs in the United States than any other sector.¹ If any one industry is important in determining the future balances among the world's great powers, it must be electronics, the largest industry in these nations today and tomorrow. As the United States prepares for the twenty-first century, it is essential we gain and maintain an edge in electronics, especially in the base of all electronics, semiconductors and related devices.

However, it appeared in the early 1980s that a familiar scenario was playing out again this time in the U.S. semiconductor industry, “success led to market dominance and then to complacency.”² In turn, the Japanese began to take over. “By 1985 [U.S. companies] had lost the world leadership, which had looked unassailable only five years earlier.”³ It seemed certain that “Silicon Valley would soon resemble Detroit.”⁴ Indeed, given both Japanese successes in automobiles and consumer electronics and the U.S. track record of ignoring such threats, the thought that the United States could make a comeback in semiconductors bordered upon the incredible—and the absurd. By the end of 1993, however, it has become clear that this is precisely what happened. In 1992 the United States regained the lead in world semiconductor sales from Japan and outspent their Pacific rivals for the second consecutive year on research and development (R&D) and capital expenditures (investment in manufacturing plants, equipment, and so forth), both of which are trends expected to continue at least into the mid-1990s.⁵

Whenever conventional wisdom is turned upside down, a search for answers as to why the theorists were wrong is inevitably undertaken. Why or how did the United States make its return to the semiconductor industry? In answering this question, it is necessary to demonstrate that the comeback really occurred. Upon establishing that the United States has made first significant progress, I will argue that no one factor contributed to the United States regaining its leadership. Instead, five different, but interrelated, factors made significant contributions. First, structural changes in the computer industry created an environment conducive to employing U.S. semiconductor firms. Second, government actions were generally helpful to the industry while appropriately non-intrusive. Third, companies in the United States did a superior job of forming key strategic alliances and in research and development. Fourth, the interplay of software and hardware aided U.S. semiconductor makers considerably more than Japanese. Finally, economic factors made it easier for U.S. firms to succeed than their Japanese counterparts.

The Fall and Rise of U.S. Semiconductors

In 1980 the United States was the undisputed world leader in semiconductors with a more than majority share of the market. In 1978 seven of the ten largest semiconductor makers were American and three were Japanese. By 1988 the roles were reversed: seven of the top ten were Japanese, including five of the top six. By 1989 the U.S. share of the world semiconductor market had plummeted to 35 percent, whereas Japan had captured 51 percent. Worse yet, in the late 1980s and early 1990s International Business Machines (IBM) and Digital Equipment Corporation (DEC), the largest U.S. computer makers, were posting major losses. In the 1990s, however, things have turned around for U.S. manufacturers as shown in Figure 1. The United States is even selling an ever-increasing amount abroad; the trade deficit in semiconductors dropped by 50 percent between 1990 and 1991 as the data in Table 1 indicates.

¹. “Attaining Preeminence in Semiconductors,” Third Annual Report to the President and Congress (Arlington, VA: National Advisory Committee on Semiconductors, February 1992), p. 8–9.

². David H. Brandin and Michael A. Harrison, *The Technology War* (New York, N.Y.: John Wiley & Sons, 1984), p. 150.

³. Georges Anderla and Anthony Dunning, *Computer Strategies 1990-9* (New York, N.Y.: John Wiley & Sons, 1987), p. 20.

⁴. John W. Verity, “The Japanese Juggernaut That Isn’t,” *Business Week*, 31 August 1992: 62.

⁵. Richard Brandt, “A Power Surge in Chips,” *Business Week*, 11 January 1993: 80.

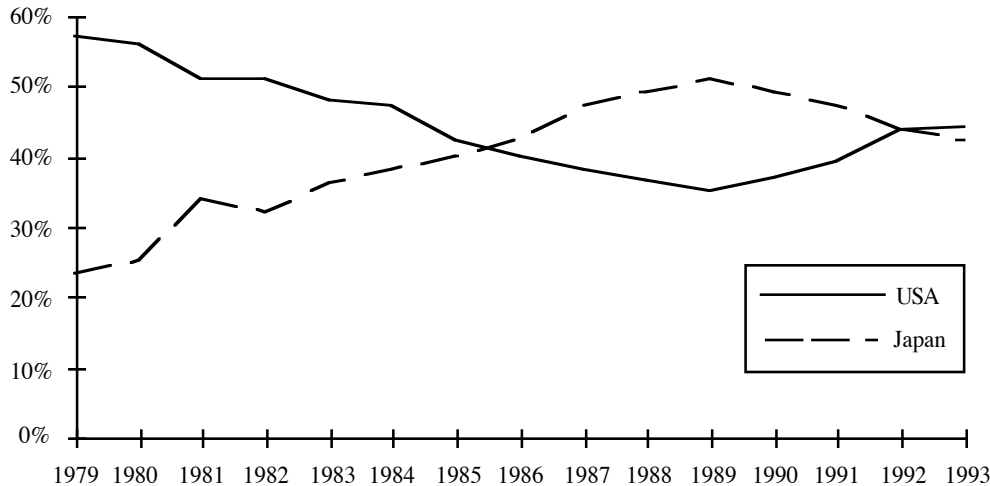


FIGURE 1. Share of World Semiconductor Market for the United States and Japan, 1979–1993. *Source:* Semiconductor Industry Association and Dataquest Incorporated. Tom Forester, *Silicon Samurai* (Cambridge, Mass.: Blackwell, 1993), p. 44.

The equipment that is used to manufacture semiconductors is also quite strategically important for without the state-of-the-art in machines that make the chips, it would be impossible to possess a leading edge chip industry. In 1980 the United States controlled 61 percent of the semiconductor manufacturing and equipment (SM&E) market. By 1985 this share was down to 55 percent and was only 35 percent last year.⁶ In fact, however, things aren't as bad as they seem. The share of Japan's market for SM&E controlled by U.S. firms is 18 percent, up from 15 percent in 1990 even though overall Japanese investment levels are down. Moreover, the United States has taken the lead in important new chemical vapor deposition fabrication equipment⁷ and South Korea, which is rapidly expanding its manufacturing capabilities, has recently placed SM&E orders almost exclusively with the United States (100 percent of Samsung's recent \$900 million order is with the United States).⁸ Additionally, U.S. SM&E maker LSI Logic has just debuted a new 0.5 micron chip making process. (Currently, 0.6 microns is the cutting edge standard.)⁹ As a result of the resurgence, "Not only are U.S. chip makers now buying most of the equipment for the new plants from U.S. suppliers (Motorola buys 88 percent, Intel 75 percent+), but even Japanese companies are purchasing more U.S. equipment."¹⁰

It is important to note that the United States has not completely reclaimed semiconductors. It owns a staggering 94 percent of the world central processing unit (CPU) market, the brains of most computers. The United States is also doing very well in custom circuits (ASICs), erasable programmable read-only-memory (EEPROM) chips, and digital signal processors (DSPs). However, the Japanese, and increasingly the South Koreans, control the vast majority of the dynamic random access memory (DRAM) market. This is where Japan obtains a large chunk of its sales. Even here, though, the United States is making inroads. IBM and Texas Instruments are "quite well placed in memory chips"¹¹ and Idaho-based memory maker Micron Technology

TABLE 1. Trade Data for U.S. Semiconductors in Constant 1987 Dollars ('000,000)

	1989	1990	1991	1992
Imports	11,972	12,001	12,335	12,820
Exports	9,037	10,710	11,752	12,000

Source: U.S. Department of Commerce, *U.S. Industrial Outlook 1992* (Washington, D.C.: G.P.O., January 1992): 16–2.

⁶ "Bad Call," *Forbes*, 22 June 1992: 23.

⁷ Julia Pitta, "Vapor Ware," *Forbes*, 25 May 1992: 254.

⁸ Jeff Dorsch, "Hyundai, Samsung on Capital Spending Binge," *Electronic News*, 29 November 1993: 1.

⁹ "LSI Launches New 3.3V 0.5 Micron Process," *Electronic News*, 15 November 1993: 1.

¹⁰ Richard Brandt, "Chipping Away at Japan," *Business Week*, 7 December 1992: 120.

will have grown 45 percent this year.¹² It seems evident to most analysts that the United States, for whatever reasons, is back in the semiconductor business. But it is the reasons for such an incredible turnaround that hold the true interest.

Structural Changes in the Industry: 1980 to 1990

The 1980s were a decade of extraordinary change in the landscape of electronics, computers, and semiconductors. When the decade began, most computers were monstrous devices the size of several household refrigerators connected together. These “mainframes” contained high performance processors, large amounts of electronic random access memory (RAM), and vast amounts of permanent storage (tape or disk drives). Individual users were hooked into the system via “terminals,” basically video monitors, and keyboards (with no independent processing unit) wired to the mainframe. At this time minicomputers were gaining in popularity. These were smaller, single refrigerator-sized boxes. They possessed speed and memory that was correspondent with their smaller size and price. Both types of machines were generally in use only by large companies or government institutions as their cost was prohibitive to all others. Simultaneously, personal or micro-computers were rapidly gaining popularity. Among the great success stories of the late 1970s was the Apple II, the first true personal computer. The success of this segment of the market prompted industry giant IBM to introduce its own personal computer in late 1981. These machines were typically a great deal less capable than minicomputers, to say nothing of mainframes.

Incredibly, it was the latter group of machines that would end up destroying the dominance of IBM and DEC by wiping out the dominance of the platforms those companies monopolized (mainframes for IBM and minicomputers for DEC). “Almost all direct competitive initiatives failed to dislodge the competitive firms,” notes Shane Greenstein, professor of economics at the University of Illinois. “The ultimate sources of competition followed from competitive initiatives [personal computers] that at first appeared to offer no threat to established firms.”¹³ In other words, personal computers forever changed the industry by decentralizing or delocalizing the processing, memory, and storage functions of the mainframe out to the “terminals.” This change is often associated with some failure on the part of IBM to prevent such a change from occurring. It is important to note that even the significant resources of IBM would have found it nearly impossible to stop the changes underway in the market. “Users prefer open systems and non-proprietary modular component design because this makes users secure against the later predations of the sponsor.”¹⁴ Concerns about having to buy all hardware, software, and support services from one company was a real problem for mainframe customers. It was not, in contrast, a concern for buyers of personal computers because “in this industry, the smaller the systems, the more modular the design and the more open was the control of standards.”¹⁵ Even if IBM could have somehow restrained the natural impetus of customers, it cannot be faulted for not concentrating on such action. “Large system vendors were locked into their customers.”¹⁶ IBM, naturally enough, concentrated its efforts on its profitable mainframe operations. Ironically, by doing so, it may have increased the pressure customers felt to escape IBM’s dominance and thereby (inadvertently to be sure) accelerated the demise of the mainframe platform and correspondingly its own profitability. The pressure customers felt was exemplified by the success of the original Apple Macintosh advertisement that ran only once, during the 1984 Superbowl. It portrayed a futuristic world dominated by IBM until one brave woman stepped forward and tossed a sledgehammer into a huge video screen. It may as well have been a dagger plunging into IBM’s heart, as it signaled only the beginning of the shift from mainframes to personal computers.

As the 1980s progressed personal computers (PC’s, used in the sense of all microcomputers, not just IBM and compatibles) came to dominate the computing scene. As Table 2 indicates, by 1984 sales of PC’s overtook mainframes in dollar amount and minicomputers suffered the same fate by 1986. This shift represented a

¹¹. Forester, p. 82.

¹². “A Power Surge,” p. 80.

¹³. Shane M. Greenstein, “Did Comp Tech Diffuse Quickly? Best and Average Practice in Mainframe Computers, 1968-1983,” *Faculty Working Paper* 93-0181, Political Economy Series #64, Bureau of Economic and Business Research, College of Commerce, University of Illinois at Urbana-Champaign, 1993: 1.

¹⁴. *Ibid.*, p. 39.

¹⁵. *Ibid.*

¹⁶. *Ibid.*

TABLE 2. Domestic (U.S.) Computer Shipments in Units and Constant 1992 Dollars ('000,000)

Year	Microcomputers		Minicomputers		Mainframes	
	Units	Dollars	Units	Dollars	Units	Dollars
1960	NA	NA	NA	NA	1,790	590
1965	NA	NA	600	66	5,350	1,770
1970	NA	NA	6,060	485	5,700	3,600
1975	10,500	19	26,990	1,484	6,700	4,960
1976	53,000	97	39,320	1,887	6,750	5,060
1977	120,600	223	56,780	2,780	8,900	6,940
1978	237,900	440	68,340	3,690	7,500	6,230
1979	329,400	630	81,250	4,712	7,200	6,340
1980	796,000	1,550	105,870	6,238	9,900	8,840
1981	1,157,000	2,550	121,990	7,290	10,700	9,640
1982	1,950,000	4,390	128,000	7,770	10,600	9,860
1983	3,249,000	7,470	146,800	8,979	9,980	9,780
1984	5,190,000	11,940	205,400	12,817	11,330	11,900
1985	4,750,000	11,260	190,800	11,696	10,910	11,890
1986	5,060,000	12,060	198,200	11,872	10,990	12,200
1987	5,460,000	12,890	205,800	12,080	11,200	12,660
1988	5,990,000	14,050	218,100	12,656	11,540	13,270
1989	6,530,000	15,963	227,700	13,093	11,890	13,790
1990	7,050,000	17,980	232,000	12,650	12,130	14,190

Source: CBEMA Information Technology Industry Databook 1992.

fundamental change for the computer and semiconductor industries. Instead of market hegemony by vertically integrated giants (now “dinosaurs”) such as IBM or DEC, the U.S. computer and semiconductor industries became dominated by small, specialized, and very agile firms. Intel, the producer of the central processing units (CPUs) for IBM-compatible PCs, is the closest thing the U.S. industry has to a monopoly and it is far from being so, given the new challenges it faces from DEC’s Alpha processor and especially the IBM-Apple-Motorola alliance’s Power PC chips.

This structural change has altered the United States and the world computing environment to one that is beneficial to the U.S. semiconductor industry. The primary feature of the new computing world emerging in the late 1980s was the intense competition between both hardware and software vendors for ever more knowledgeable consumer dollars. This trend is more true in the wake of the summer of 1992 computer price wars. “There’s more competition in the United States [versus Japan]. There are a lot of guys ready to slit your throat in order to beat you to the market,” says Kenneth Flamm, a senior fellow at the Brookings Institution.¹⁷ That translates into the fact that “systems [in Japan] are six to nine months behind what we see in the United States.”¹⁸ Intel Corporation CEO Andrew Grove says, “unless you can roll out products three times a year, you’re a has-been. The fashion industry doesn’t move at the speed this one does.”¹⁹ If one accepts that the U.S. computer market has changed in such a way as to replace IBM and DEC with dozens of smaller companies, how does that translate into a U.S. advantage versus Japanese giants NEC, Hitachi, and Fujitsu?

The answer seems to be that the indomitable U.S. entrepreneurial spirit is a key to success in computers. The “innovative U.S. computer micro culture” possesses “hundreds of young scientists, fiddling at their workbenches, dreaming of becoming the next Steve Jobs, knowing that they could go from zero to \$100 million in sales in just a few years.” After all, dozens of others, including Apple, Compaq, and Dell have done so.²⁰ The United States was founded on these very ideas—that individuals, free of restrictions, could accomplish the incredible. The ability of any small business or set of individuals in a garage to successfully market a product leads to the introduction of a great deal of technologies by the United States that would never have made it past the watchful eyes of the “High Command” of Japanese companies (or even massive U.S. ones). “Such innovation and creativity marks the micro industry and, for all their excellent attributes, these are qualities

¹⁷. Verity, p. 66.

¹⁸. Ibid.

¹⁹. Ibid.

²⁰. Robert Sobel, *IBM vs. Japan* (New York, N.Y.: Stein and Day, 1986), p. 225.

rarely found in the Japanese business scene.”²¹ Yet in the United States, since the demise of the giants, IBM and DEC, a huge number of small firms exemplifying these qualities have cropped up.

However, why didn't (don't) the Japanese simply become more creative and innovative? The problem with that, say many experts and even more laymen, is that the Japanese are merely masters of copying the pioneering work done by others. This leads to the idea that the United States has an inherent advantage when it comes to staying ahead of the competition at the leading edge of technology. The origins of this advantage lie in the differences between the United States and Japanese educational systems. “Education is a key strategic factor in the technology war.”²² The U.S. system is famous for its excellent research institutions and open style where students are encouraged to think freely. In Japan, debate is not encouraged and “obedience often gets the better of free thought.”²³ This leads to a tendency to obey central authority and act as a group. It also restricts the free thought vital for dreaming up the next breakthrough. For example, author Martin Fransman notes that during the post-World War II period in Japan there exist only two(!) examples of “spontaneous inter-firm cooperation; that is, cooperation arranged privately ~~□□□□~~ without the intervention of government agencies.”²⁴ The products of Japan's strict educational system that go on to run its companies are seemingly incapable of acting without centralized instruction. This behavior leads to a weakness in the basic structure of Japanese business that has left it unprepared to compete with the United States in the volatile and delocalized computer market that began to take shape in the late 1980s.

Past experience supports this conjecture. In Japan the general thought has run, “Whatever the United States or anyone else could do, [Japan] can do better and less expensively.”²⁵ The Japanese certainly seemed to support that belief in their seizure of the vast majority of the world market for DRAM chips. It is fundamental to understand, however, that this was possible mainly because that market simply demanded that products become smaller and cheaper, not different. In 1981 the president of Fujitsu said Japanese companies lacked the “dynamism and creativity” of the United States and he went on to say, “Japan can only follow Western science.”²⁶ For the Japanese to succeed, “first others have to blaze the path with innovation and perception, and the sub-industry had to settle down into some recognizable form.”²⁷ However, in the late 1980s and beyond, the U.S. market began to demand ever increasing performance and decreasing prices from the CPUs, ASICs, and DSP chips at the heart of computers, forcing product cycles down to as little as six months.²⁸ These highest-technology and highest-value added products are precisely the place the United States has made its comeback. The Japanese could not keep up simply because this industry refuses “to settle down into a recognizable form.” As author Robert Sobel states, “the Japanese needed a fixed target, and this one was constantly moving.”²⁹

Given the above considerations, it seems that the near-death experiences of IBM and DEC were not bad for the United States after all. The ability to contain the natural market forces that demanded a less centralized computer industry were simply not possible for these giants (nor any other company). By the end of the 1980s the inevitable shift to personal computers as the platform of choice was complete. This in turn produced an environment in which small, entrepreneurial firms could flourish. Apple, Compaq, Sun Microsystems, Dell, and Silicon Graphics (SGI) are some of the well-known examples of success. This environment naturally favored U.S. semiconductor makers who have traditionally been superior to their Japanese rivals in designing new products. While this design advantage seems generally present in most industries (as a result of the different educational systems and capitalistic attitudes of America and Japan), semiconductor makers in the last five years have been the exception to the U.S. business rule. They have capitalized on their design advantage and manufactured the innovations of U.S. engineers to make a strong return to the market.

21. Ibid.

22. Brandin and Harrison, p. 108.

23. “Japan's Schools.” *The Economist*, 23 October 1993: 53.

24. Martin Fransman, *The Market and Beyond* (Cambridge, U.K.: Cambridge University Press, 1990), p. 279.

25. Sobel, p. 217.

26. Ibid., p. 228.

27. Ibid., p. 217.

28. Verity, p. 66.

29. Sobel, p. 217.

Government Action and Inaction

Whenever U.S. industry is in trouble, it goes running to the government in search of help. Yet rarely do industries receive much more than promises. Chrysler received a guaranteed loan in the early 1980s, but the U.S. auto industry as a whole received very little from the Reagan administration. The Japanese did institute “voluntary” export controls at the prodding of the United States, but this action was based as much on wanting to avoid a U.S. consumer backlash as heavy-handed U.S. government tactics. And yet, the auto industry seems to have done very well for itself without major government intervention. Perhaps the semiconductor industry should be left alone in the same way. Certainly executives in the business didn’t think so. In 1990 Andrew Grove, CEO of Intel Corporation, sent White House budget director Richard Darman a violin, “suggesting he might do some more fiddling while the American high-tech industry burned!”³⁰

The feeling on the part of most industry executives is that the government must assist industry in raising “cheap and patient” capital. According to a government survey of executives, the high cost of capital is the number one problem their companies face, ranking 7.9 out of 10.³¹ Poor relations between SM&E suppliers and semiconductor makers (7.4) was the number two problem.³² Significantly, these same executives ranked unfair foreign pricing (4.2) and unfair foreign trade barriers (5.1) as the least important challenges.³³ Interestingly, the latter are the areas in which government is generally thought to act to the benefit of industry whereas the former are considered challenges for the industry to overcome on its own. Fortunately, however, someone in Washington was awake at the wheel in the 1980s, for the government’s efforts (perhaps by chance only) assisted the semiconductor makers with their problems of obtaining cheap capital for R&D and developing closer ties with equipment suppliers.

In 1958 the government created the Defense Advanced Research Projects Agency (DARPA) to “carry out long-term, high-risk, and high-impact R&D.”³⁴ Although mostly aligned toward defense-related applications, “it is important to note that DARPA’s success in computer technology is one of the greatest accomplishments of any government-funded activity in any field, matched only, perhaps, by the Manhattan Project.”³⁵ In the 1980s DARPA spent an average of 75 percent of its budget on research through industry. And although most was defense-related important breakthroughs, especially in networking, occurred under the DARPA banner (ARPANET derivatives became the popular TELENET in the late 1980s).³⁶ In 1983 in response to the Japanese “Fifth Generation” project that focused on developing the next level of supercomputers, the U.S. government (through DARPA) established the Strategic Computing Initiative (SCI). Spending more than \$100 million per year in the early 1980s, SCI researched new materials and fabrications techniques as well as parallel processing architectures.³⁷ The residual effects of this research can still be seen today in the large U.S. lead in MPSC (massively parallel supercomputer) architecture. These are but a few government funded programs that assisted U.S. semiconductor makers in the past.

The government in the 1980s spent a large amount of money on R&D, but it went primarily for military purposes. Nonetheless, by 1987 the United States was spending a larger portion of gross national product (GNP) on R&D than in any year since 1968.³⁸ Non-defense R&D as a percent of gross domestic product (GDP) for the United States is 1.8 percent, well behind Japan (2.8) and Germany (2.6), although comparable to France (1.9) and Britain (1.5). It is essential to remember, however, that overall R&D spending as an absolute amount in 1989 in the United States was greater than that of Japan, Germany, France, and Great Britain *combined*.³⁹ And much of this research, even that in defense-related areas, is handed over to private industry (as the DARPA and

³⁰ Forester, p. 82.

³¹ “Sematech’s Efforts to Strengthen the U.S. Semiconductor Industry,” (Washington, D.C.: U.S. General Accounting Office Press, September 1990), p. 22.

³² Ibid.

³³ Ibid.

³⁴ Brandin, p. 115.

³⁵ Ibid.

³⁶ Brandin, p. 116.

³⁷ Ibid., p. 116–117.

³⁸ Charles Fleer, *Computer Hardware* (New York, N.Y.: McGraw-Hill, 1990), p. 67–68.

³⁹ Ibid., p. 67–68.

SCI experiences make clear). “Strong emphasis is placed on the transfer of the results of government-funded R&D to industry and in cooperation with industry to insure the continued strength of U.S. high-technology trade in the international marketplace.”⁴⁰ By directly investing in R&D and transferring those results to industry, the government indirectly assisted the semiconductor industry in the 1980s to solve its problem of obtaining capital.

However, in the United States central planning has never seemed to work. It would have been a big plus if the cost of capital were directly reduced. The government did take steps in that direction in the 1980s by instituting an R&D tax credit. By giving companies credits for money used in R&D (basically not counting any money used for R&D as taxable), the government lessened the expense of R&D.⁴¹ More significantly, however, is the fact that interest rates remained low during the latter half of the 1980s. It is difficult to prove that government policies are responsible for the success of the economy and even harder to believe that the government kept interest rates low, allowed the dollar to fall, and kept the economy expanding specifically with the thought of helping the semiconductor industry. However, intentional or not, these positive economic factors assisted U.S. industry in obtaining investment capital.

Although not entirely by design, the government improved cooperation in the semiconductor industry by launching a consortium with private companies called Sematech in 1987. The largest U.S. semiconductor manufacturers together contribute \$100 million per year to Sematech, with the government matching those funds.⁴² Still, the President of Sematech admitted in 1990 that “we have not been the cure-all for the ills of the U.S. semiconductor industry. The problem is too large for Sematech.”⁴³ Indeed, a large number of industry analysts say that Sematech has not been able to accomplish its goal of reviving the U.S. SM&E industry. What it does seem to have done, however, is satisfy the number two problem semiconductor executives pointed to—bad relationships with equipment suppliers. Neil Booke, president of General Signal’s SM&E operations says, “before Sematech, buyers wouldn’t accept your figures [of manufacturing yields]. Now when asked, we’re all using the same sheets of music.”⁴⁴ IBM purchased twenty advanced lithographic stepper machines for chip making in late 1992 from Applied Materials. Because of the investment risk of developing the tools, “without Sematech, the deal would have fallen through” because Applied couldn’t be sure it would have a customer waiting.⁴⁵ It seems that the best thing the government could do, and what it did do through Sematech and other national research programs, is to “play an important leadership role in fostering the cooperative spirit that would encourage U.S. companies to participate more effectively in sharing their future with other U.S. companies.”⁴⁶

While many people are quick to say that government failed to do anything about unfair Japanese trade barriers or foreign “dumping” of products onto the U.S. market, remember that the industry itself thought these problems to be their least important. The most important problem, the high cost of capital, was not solved by direct government action. Rather, the government assisted industry in R&D projects and provided a stable economic environment with low interest rates in which U.S. companies could make progress. It also addressed the second most important problem, the lack of cooperation and ties between the SM&E and actual manufacturing parts of the industry. By bringing equipment suppliers and equipment users together in projects like Sematech, the government, although perhaps not intentionally, helped focus U.S. industry on the challenge at hand and provided an environment of greater cooperation. An important idea is that participation in all these programs was optional, allowing companies the freedom of choice essential to U.S. capitalism. This avoided putting too many constraints on the private sector, but it did burden them with the responsibility for their own success or failure.

⁴⁰ Ibid., p. 89.

⁴¹ House Committee on Science, Space, and Technology, “The Federal Research Policy for Semiconductors,” hearing in U.S. Congress (Washington, D.C.: Government Printing Office, 29 March 1990), p. 42.

⁴² “Sematech’s, Efforts,” p. 8.

⁴³ “Federal Research Policy for Semiconductors,” p. 61.

⁴⁴ Elizabeth Corcoran, “Semiready,” *Scientific American*, November 1992: 122.

⁴⁵ Ibid.

⁴⁶ “Federal Research Policy for Semiconductors,” p. 29.

Companies' Efforts: Alliances and Smart R&D

During the latter part of the 1980s and on into the 1990s the efforts of U.S. semiconductor companies have focused mainly on two critical aspects that assisted them in their successful battle against the Japanese. First was the formation of a number of strategic alliances, and second was a better, and later bigger, use of R&D and capital improvement funds. A great number of alliances between U.S. firms and either other U.S. firms or foreign companies (usually Japanese) were founded in the late 1980s and early 1990s. Too numerous to list here, these alliances sent the signal that at this time in the U.S. semiconductor market, firms were finding it beneficial to share (mainly) R&D funds. In Japan, the powerful Ministry of International Trade and Industry (MITI) coordinates the policy and alliances of most Japanese companies from Tokyo. Meanwhile, in America, the U.S. government left companies alone to pursue their own alliances. While many argue that this is a weakness, we have seen that a more open entrepreneurial structure was actually quite beneficial to U.S. semiconductor makers. The same is true in strategic alliances that during this period allowed U.S. companies to experience the benefits of cooperation without losing control over their own destiny to the government (that as was noted above, refused to directly intervene).

One of the most significant benefits of a strategic alliance is the ability to share R&D. "With the cost of developing new products increasing, not even giants like IBM could afford to develop and produce a whole range of products by itself."⁴⁷ In 1991 IBM partnered with Toshiba and Siemens (Germany) to produce the next memory chip product, sixty-four-megabit DRAMs. At approximately the same time, IBM allied itself with its ancient enemy Apple Computer and rival Motorola to produce the next generation of computer processors (Power PC), operating systems (Taligent), and multimedia products (Kaleida). Intel, Microsoft, and Hewlett Packard formed the ACE (Advanced Computing Environment) to produce a rival set of technologies. Alliances such as these allow(ed) the participants to leverage their R&D investment by sharing costly equipment and spreading the risk of product development.⁴⁸ Meanwhile, alliances allow for more vertical integration in the business although each member of the group can continue to do what it excels at doing.⁴⁹ An example is the IBM-Apple-Motorola alliance. IBM designed the POWER chip set (used in high-end RS/6000 workstations), which it handed over to hardware specialist Motorola to turn into a personal computer CPU and subsequently manufacture. Meanwhile, Apple is to concentrate on bringing its first-rate Macintosh operating system to the new chip as IBM markets the systems through its extensive network.

Another type of alliance system that was invented in the U.S. semiconductor industry is called "farming-out." Companies who specialize in one area will concentrate only on that strength and farm-out the remainder of the work necessary for their products to be complete. One example is workstation manufacturer Sun Microsystems. Last year Sun had sales of \$3.6 billion,⁵⁰ but did very little of its own computer assembly. It concentrates upon its particular strength, which is microprocessor design, and contracts other companies to put its computers together.⁵¹ Another example is Novellus Systems Incorporated of San Jose that manufactures SM&E machines, specifically those that employ chemical vapor deposition (CVD) methods. With annual sales of merely \$80 million, Novellus finds life difficult facing the Japanese giants six to ten times its size. To survive, most of the work on the CVD machines is done by allies with only eleven Novellus employees completing the final assembly work.⁵² The company focuses on the marketing and design of the machines, where they are able to do a superior job. Novellus is so good, in fact, that one-third of its revenues come from Japan,⁵³ an impressive feat considering the overall U.S. share of the Japanese SM&E market is 18 percent.⁵⁴

While these alliances have been very successful for U.S. semiconductor makers, not all alliances are good. That is why the U.S. system in which private companies make private arrangements is helpful. In 1990 a

⁴⁷ Forester, p. 79.

⁴⁸ Anderla, p. 73.

⁴⁹ Forester, p. 79.

⁵⁰ BIZNET Company Data," CD ROM (Lotus One Source CD/Corporate: U.S. Public Companies, October 1994).

⁵¹ *U.S.-Japan Strategic Alliances in the Computer Industry*, National Research Council, National Academy of Sciences (Washington, D.C.: National Academy Press, 1992) p. 101-109.

⁵² Pitta, p. 254-255.

⁵³ *Ibid.*, p. 255.

⁵⁴ "Bad Call," p. 23.

consortium called U.S. Memories broke up.⁵⁵ This is pointed to by pundits as yet another signal of impending doom for the United States. However, it is clear that the alliance was not working correctly or the firms involved would not have left. So although cooperation is regularly seen as a success, why should companies succeed if it feels like failure? Not all alliances are beneficial, and companies must have the freedom to dump partners when things aren't going well. In Japan companies are not forced "at gun point" to enter alliances, but it is very nearly the truth. Japan's powerful MITI is the central economic coordination arm of the government, and it arranges Japanese R&D alliances. It maintains "a large, centralized, and permanent research facility."⁵⁶ It also, from time to time, "establishes a national project, coordinated by a committee."⁵⁷ At other times it establishes "a special purpose laboratory that supports a specific research objective."⁵⁸ Notice that all of MITI's methods involve "centralized" or "national" efforts. Japan's government tends to mediate the R&D of the entire nation and individual companies are compelled to participate at the government's whim. This is often touted as a strength, but occasionally it is not. This will become evident as we now examine the second area of company action in the late 1980s and early 1990s—research and development.

The United States (as noted earlier) spends a huge amount on R&D each year, but much of it is directed toward the military. For most of the time frame under scrutiny Japanese companies vastly outspent their U.S. counterparts, again, often at the "request" of MITI. However, their R&D did not always succeed. They often plunged a huge amount of a classic Japanese strength—cheap and patient capital—into bottomless pits of failed research. One example is the Fifth Generation Project. Undertaken in the early 1980s, this project was and is intended to take the Japanese to the next level of computing. The Fifth Generation architecture will "abandon the traditional approach and process information along parallel lines."⁵⁹ It also depends upon artificial intelligence, which mainly exists in the domain of software. The Japanese have poured vast sums of research money into this project, \$1 billion in the 1980s from MITI alone,⁶⁰ yet the United States is still far out in front. Thinking Machines Corporation of Cambridge Massachusetts currently produces the world's fastest supercomputer, the CM-5. This collection of thousands of high-speed reduced instruction set computing (RISC) microprocessors connected together has recently resulted in the delivery of a system to the Jet Propulsion Laboratory capable of a mind-blowing (and record-setting) seventy-eight gigaflops or seventy-eight billion floating point operations (add, subtract, multiply, and so forth) per second. Intel's Touchstone subsidiary also is active in MPSCs (massively parallel supercomputers) with its Delta; composed of ordinary 1960 processors, it used to be the speed record holder. Old mainframe master IBM is joining the fray, as is "old-style," or vector, supercomputer maker Cray. Cray is currently working on a hybrid of an older type vector machine, which excels at sequential problems, and a MPSC machine that handles parallel computations to offer the best of both worlds. Author Tom Forester concludes, "one bright spot for the United States is its apparent strength in massively parallel processing."⁶¹

⁵⁵. Forester, p. 67.

⁵⁶. Brandin, p. 159.

⁵⁷. Ibid.

⁵⁸. Ibid.

⁵⁹. Sobel, p. 229.

⁶⁰. Brandin, p. 164.

⁶¹. Ibid., p. 104.

TABLE 3. Top Ten Semiconductor Capital Spenders in 1993 in Millions of Dollars

1993 Rank	Company	Country	1993 Capital Expenditures	1992 Rank
1	Intel	USA	2006	1
2	Motorola	USA	973*	2
3	Samsung	South Korea	930	4
4	Toshiba	Japan	519	3
5	Texas Inst.	USA	512	8
6	NEC	Japan	482	5
7	Goldstar	South Korea	417	9
8	Hitachi	Japan	409	6
9	Hyundai	South Korea	401	19
10	AMD	USA	383	15

Source: Jeff Dorsch, VLSI Research, in "Hyundai, Samsung on Capital Spending Binge," *Electronic News*, 29 November 1993: p. 6.

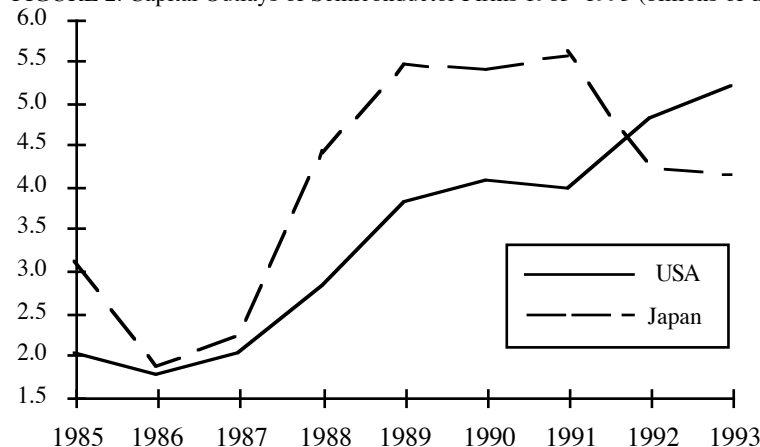
*Note: These figures do not include Motorola's \$1,000 million manufacturing facility expansion for making Power PC 603 and 604 chips.

There are, of course, a number of successful Japanese R&D projects and, as a matter of record, the Japanese have greatly outspent the United States on capital improvements (equipment, plants, and so forth) as Figure 2 shows.

For the past two years, however, the United States has outspent the Japanese on capital outlays and in 1993, U.S. companies are out ahead as found in Table 3.

This good news means that in 1992 "the industry prepared for the next expansion in demand, countering past tendencies to reduce spending during a downturn. Previously, the [U.S.] companies found themselves lagging their competitors when the upturn began."⁶² Not only has the United States been spending more than Japan recently, it has been spending money more wisely than Japan since the late 1980s. Many who have been highly critical of U.S. companies like Bell Labs for not continuing their open-ended research programs. The benefits of such research may be nice, but "however impressive the outlays on R&D may look, they conceal from view the rather unpleasant aspect of the cost of R&D projects that fail."⁶³ Even proponents of big government spending like Dr. Barry H. Whalen, Senior Vice President of the independent industry consortium Microelectronics and

FIGURE 2. Capital Outlays of Semiconductor Firms 1985–1993 (billions of dollars)



Source: Richard Brandt, "Chipping Away at Japan," *Business Week*, 7 December 1992: p. 120.

⁶². "Preserving the Vital Base," National Advisory Committee on Semiconductors (Washington, D.C.: U.S. Government Printing Office, July 1990) p. 16–22.

⁶³. Anderla, p. 71.

Computer Technology Corporation (MCC), have testified before Congress to the effect that, “use of capital is just as important as the availability of capital.”⁶⁴ So, although Silicon Valley executives complain about the lack of patient capital, they have to make careful decisions about just what kind of research they can afford. In any case, the Japanese have recently been making the mistake of “continuing to spend most of their R&D on DRAMs and commodity chips rather than innovative designs,” according to Gene Norrett, chief of semiconductor monitoring at Dataquest Inc.⁶⁵

Without doubt, it would be nice to have a limitless supply of money with which to conduct R&D, but reality has instead set in. To make up for a relative (to the Japanese) lack of capital, U.S. semiconductor manufacturers have formed strategic alliances, when convenient and beneficial, to pool limited resources and have spent what money they do have available wisely, but not miserly (not, for example, reducing spending during the 1990–91 recession and being caught unprepared for the expansion). These company decisions have resulted in U.S. semiconductor makers entering the mid-1990s more competitive than at any time since the early or mid-1970s.

Inseparable Interplay of Hardware and Software

Only the most depressed domestic analysts question the U.S. dominance in the world computer software market. The numbers lend support to this faith. In 1990 the world market for software was worth \$110 billion and the United States controlled a 57 percent share, trailed distantly by Japan (13 percent), France (8 percent), Germany (7 percent), and Britain (6 percent).⁶⁶ This is especially important to U.S. jobs in general because software is becoming the ever more costly (relatively) portion of computing. In 1960 hardware accounted for more than 80 percent of a computing system’s cost, with software making up the rest, a meager 18 percent or so. By 1970, however, the ratio of cost of hardware to software had reached 50:50. By 1985 the ratio was 15:85.⁶⁷ This has gone largely unrecognized because of the large drop in the absolute cost of computer systems.⁶⁸ Nonetheless, software is of massive importance in the computer industry. The U.S. dominance in software also brought good news for semiconductor makers. Software mastery helped the United States for two reasons. First, advances in software and hardware feed off one another. Second, software is a key (often the key) to establishing a winning computing standard, which, of course, establishes a winning semiconductor standard as well.

The interplay of software and hardware is inseparable. Advances in one lead rapidly to advances in the other. Consider a familiar scenario to computer buyers. In 1987 a new computer with a fast new microprocessor is released, say an IBM with an Intel 386 processor. Software designers now have a chip with twice the computing power than the previous crop of machines allowing them to add new features and upgrades to their software. (These enhancements would have run unacceptably slowly on the older machines because of the processing overhead of new features.) But with new software, the new machines run as slowly as the old machines, although with more capabilities. So, Intel is forced to produce yet another advance in processor speed to prevent users from switching to a competing system that may offer superior performance. Now the 486 chip comes out and meets a similar fate. Microsoft has extra processing horsepower with which it can do wonderful things, but at the price of performance. With the advent of Windows 3.0, IBM and compatibles are easier to use, but are once again slowed severely. So Intel is forced to rush out the Pentium (586) processor. We can expect that new multimedia software packages will slow the wicked fast new machines and demand an even better chip in the near future. As an industry expert says, “the trap reinforces the need for further innovation and whips up competition, with the circular action and reaction starting all over again.”⁶⁹

This very scenario has played out time and again in the United States in the late 1980s and early 1990s. The advantage the United States has over its competitors is that the level of U.S. innovation in software design is

⁶⁴. “Federal Research Policy for Semiconductors,” p. 80.

⁶⁵. “A Power Surge,” p. 80.

⁶⁶. Forester, p. 96.

⁶⁷. Anderla, p. 58.

⁶⁸. *Ibid.*, p. 59.

⁶⁹. *Ibid.*, p. 70.

unrivaled elsewhere. This conjecture is supported by the U.S. dominance of the world market and is a result of the free thinking products of the educational system, the entrepreneurial “hacker” spirit in America, and the relative lack of government regulation of the software industry. As U.S. software designers got their hands on a better chip, they were able to stretch their lead over (especially) Japanese rivals. This, in turn, led to a more urgent need in America for the next generation of microprocessors. When the superior U.S. hardware was rolled out ahead of the competition it helped the software people jump even further ahead, which again made for better hardware and so on in a never ending cycle. Japanese companies might hope to get into the cycle somewhere and then simply out-design their U.S. competition. However, given the Japanese track record for original design, this seems unlikely.

Software also plays a vital role in determining the future of computing standards. For years, RISC microprocessors have been far superior in speed and comparable in price to the older complex-ISC (CISC) processors used in today’s IBM PCs and Macintoshes. Curiously, however, they did not sweep the industry. The importance of this point cannot be overstated. A clearly superior semiconductor design, which has existed for many years, has not yet been able to dominate, or even significantly impact, the personal computer market. This does seem certain to change in the near future with the Apple-IBM-Motorola Power PC and the entry into the personal computer business of heavyweight DEC with its Alpha RISC chip. But why has it taken so long (more than six years since the standard-setting Sun SPARC chip was introduced) in an industry that moves so rapidly? Additionally, RISC chips have completely dominated the science and engineering workstation market for five years, so why have personal computers not followed along? The answer clearly lies in software. Until very recently, RISC chips, fundamentally different from CISC chips, were completely incompatible with the installed base of personal computer software. Worse yet, popular software such as Microsoft Word or Lotus 1-2-3 simply was not available for RISC workstations. Scientists and engineers loved and bought workstations because the scientific and engineering software they needed was ported to the RISC design and the machines were very fast (the average single-processor workstation has three to five times the performance of top-of-the-line PCs, to say nothing of multi-processor versions). This demonstrates that the right combination of software to fit the user’s needs and hardware to provide the user’s wants must come together to form a successful package. Without software, average PC users bypassed workstations, and if those RISC chips driving workstations were not so fast, scientists would just use ordinary PCs.

Microsoft’s Windows NT and Apple’s forthcoming PowerOpen promise to bring mainstream applications to RISC processors. Although the new Pentium is an old CISC design, Windows NT can also run on DEC Alphas, Sun SPARCs, and reportedly Motorola Power PCs, all three of which are RISC chips. Apple’s PowerOpen will be designed specifically to run on RISC chips. Combinations of the Apple or Microsoft software and some vendor’s RISC hardware is likely to set the next standard in computing, replacing the IBM-compatible architecture that has endured for more than twelve years. As the 1992 Industrial Outlook notes, “Each alliance seeks to provide a full range of products centered around one RISC architecture in hopes of establishing it as the industry standard.”⁷⁰ These factors make life very difficult for Japanese semiconductor makers. Trying to produce chips that will not only be compatible with foreign operating systems but also run them well enough to compete with U.S. hardware is tough enough. It gets even more difficult for Japan Inc. when one considers that the emerging standards are coming from alliances. If Apple’s software wins, it only makes sense that the hardware designed for it from Motorola and IBM will come out on top as well. Since the Japanese cannot hope to launch their own software-hardware combination into the U.S. market (because of their weakness in software), they must always settle for the role of outsider when it comes to manufacturing anything besides DRAMs or commodity chips, the “interchangeable parts” of computers. And when one takes into account that better U.S. software results in better U.S. hardware, the Japanese have a real problem. Software is one very important reason the U.S. semiconductor industry is alive and much better off today than five years ago.

Economic Conditions in the United States and Japan

From 1987 to 1989 domestic shipments of personal computers in the United States rose from 5.46 to 6.53 million. Simultaneously, both U.S. and Japanese semiconductor firms were experiencing a boom. U.S.

⁷⁰ *U.S. Industrial Outlook*, Department of Commerce (Washington, D.C.: U.S. Government Printing Office, 1992).

manufacturers saw shipments increase (in constant 1987 dollars) from \$17.9 billion in 1987 to \$20.1 billion in 1988 to \$23.3 billion in 1989, increases of 12.2 and 15.8 percent respectively.⁷¹ The Japanese experience was similar, as sales in the U.S. market remained strong they saw sales rise from \$19.0 billion in 1987 to \$25.8 billion in 1988 to \$29.5 billion in 1989.⁷² By 1990, however, the U.S. recession had set in and, with the world's largest computer (and therefore semiconductor) market in trouble, U.S. makers saw the real value of their sales drop to \$22.8 billion in 1990, a 2.0 percent drop from 1989.⁷³ The Japanese also saw sales fall back to \$28.6 billion in 1990, a 3.1 percent drop.⁷⁴

As the United States wallowed in recession in 1991 semiconductor sales picked up only slightly, showing a 6.9 percent increase from 1990.⁷⁵ The big news entering 1992, however, was that the unstoppable Japanese economy had slid into recession. At this writing Japanese industrial production is down to 90 percent of its early 1992 level.⁷⁶ The country's GDP is still shrinking and next year's World Bank forecasts have been downgraded from +1.5 percent GDP growth to -0.5 percent growth. Meanwhile, U.S. computer companies have been expanding their share of the market in Japan (and they are bringing U.S. computers driven by U.S. chips with them). Apple Computer, for example, riding on a wave of demand for its popular Macintosh computers with their Japanese language operating system and compact size, controlled about 8 percent of the market in 1992, a share expected to have increased to 12 percent this year.⁷⁷ This trend spells bad news for the Japanese semiconductor makers.

But it gets worse for the "Rising Sun." The summer of 1992 price wars in the U.S. computer industry resulted in much lower prices for consumers and an increase of 25 percent in unit sales.⁷⁸ Concomitantly, companies like IBM, Dell, Compaq, and Apple, to say nothing of the Asian (especially Taiwanese) clone makers, have demanded even lower prices from their chip suppliers. This hurt the Japanese semiconductor makers much more than U.S. makers because of the type of chips each sells. Apple, for example, cannot go to anyone besides Motorola for its CPUs or AT&T for its DSP chips to use in its Macintoshes. Therefore, it must pay any reasonable price the U.S. semiconductor firms demand. However, memory and simple commodity chips are a different story altogether. Memory chips are functionally identical regardless of manufacturer (quality is a different issue) and with the ever-increasing strength of the very-low cost South Korean manufacturers (see Table 3 above for the investments being made by the Koreans), Japanese firms are finding the profitability of semiconductor manufacturing increasingly unattractive. So, even as the U.S. economy is recovering from recession, Japanese manufacturers are not experiencing a corresponding boom; all the while the traditionally reliable and unassailable Japanese home market is in severe recession and even then a U.S. invasion of computer products is underway.

Looking to the Future

The late 1980s and early 1990s were the years during which one of the most profound turnarounds in economic history took shape. The United States semiconductor industry, which many had left for dead in 1988, has come back with a vengeance. The next generation of microprocessors (Alpha, Pentium, Power PC, UltraSPARC, R4400, and T5) are all domestic and the United States is once again the leader in market share and capital spending. As Advanced Micro Devices (AMD) Vice President Benjamin Anixter says, "It's hard to see a down side from here."⁷⁹ This turnaround was caused by a fortunate interplay of a complex set of factors. First, shifts toward microcomputers as the platform of choice left the U.S. semiconductor companies in a superior position to compete by virtue of their preparedness for the fast-paced, hyper-competitive U.S. marketplace. At the same time, the federal government was providing a number of computing initiatives that assisted industry with R&D

71. Ibid.

72. "Preserving the Vital Base," p. 4.

73. *Industrial Outlook*.

74. "Preserving the Vital Base."

75. *Industrial Outlook*.

76. "Japan's Schools."

77. Verity, p. 65.

78. "A Power Surge," p. 80.

79. "Chipping Away," p. 120.

and increased inter-firm cooperation while leaving individual companies free to seek their own fortunes. This companies did by forming strategic alliances when convenient and beneficial and by spending their limited R&D and capital improvement budgets wisely, while recognizing and responding to the need for more such investment. Simultaneously, superior U.S. software companies were forcing the semiconductor makers to roll out new, better products at ever-increasing rates. The U.S. firms responded successfully with the effect of leaving Japanese competition (especially in central processing units) in their wake. The leading edge U.S. software also helped entrench U.S. hardware as the industry standard. All the while, world economic conditions were kinder to the U.S. semiconductor makers than their Japanese rivals.

Because most of the above conditions are currently unchanging, there is no reason to expect the U.S. comeback to reverse in the near future. The next generation of RISC processors and compatible software is on its way to setting the new standard, and U.S. companies are investing more heavily than ever before. Meanwhile, the Japanese are facing twin challenges, one from each end of the technology food chain. At the top, the United States is clearly alerted to the Japanese threat and have become increasingly difficult to dislodge. Meanwhile, the Koreans are ripping into the core of the Japanese presence in semiconductors (memory and commodity chips) through massive investments in fabrication machines gleefully supplied by an ever more sophisticated U.S. SM&E industry. As we look to the twenty-first century with concern for America's future, the recent success of the United States in the vital semiconductor industry is one of a few, but steadily increasing, signs that indicate we are moving in the right direction—out in front.