Chips and Change

How Crisis Reshapes the Semiconductor Industry

Clair Brown and Greg Linden

The MIT Press
Cambridge, Massachusetts
London, England

MIT Press books may be purchased at special quantity discounts fro business or sales promotional use. For information, please email special_sales@mitpress.mit.edu or write to Special Sales Department, The MIT Press, 55 Hayward Street, Cambridge, MA 02142.

This book was set in Sabon on 3B2 by Asco Typesetters, Hong Kong and was printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Brown, Clair, 1946–
Chips and change : how crisis reshapes the semiconductor industry / Clair Brown and Greg Linden.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-262-01346-8 (hbk. : alk. paper) 1. Semiconductor industry—Management. 2. Business cycles. I. Linden, Greg, 1959 II. Title.
HD9696.S42B76 2009
338.4′762138152dc22 2009007072

10 9 8 7 6 5 4 3 2 1

Crisis 1

Loss of Competitive Advantage

I can only conclude that the common objective of the Japanese government and industry is to dominate the world electronics market. Given the importance of this market to US industry in general and our defense base in particular, we cannot stand by idly.

—Commerce Secretary Malcolm Baldrige
addressing the Senate Finance Committee in March 1987[1]

After its invention in the United States, semiconductor technology steadily spread to other countries during the 1950s and 1960s (Tilton 1971). Western Europe and Japan were the main adopters of the manufacturing and application know-how. In the 1980s, where our analysis of the semiconductor industry begins, strength in process technology determines competitive advantage. In this chapter we discuss how Japanese chip producers raised their share of chip industry revenues above that of US producers by the mid-1980s by improving their manufacturing techniques, which gave rise in the United States to fears of steady US decline. Yet a decade later the United States was again the global leader. We explore the factors behind Japan's rise, the responses of US policy and US corporations, and the circumstances, particularly in Japan, that contributed to a US resurgence.

1.1 Japan's Rise

Japan's rise to prominence in the semiconductor industry was widely chronicled and analyzed in the 1980s. A consensus emerged around a few key factors that we summarize here. Perhaps first among these was government support. In the 1960s, powerful government agencies demanded tough terms, including technology transfers, from foreign companies such as IBM and Texas Instruments that wanted access to the growing Japanese market (Prestowitz 1988). In the 1970s, Japan's government pursued an active policy of subsidizing research and promoting cooperation between its fiercely competitive business groups; this helped them close the technology gap with US firms in chips and related technologies (Fransman 1990). Import protection of the Japanese market and an overvalued dollar were other factors that helped Japanese producers expand their sales to the domestic and US markets and reach economies of scale in production (Flamm 1996).

Japanese firms also benefited from access to capital on more favorable terms than were available to US rivals, which helped them to pursue costly long-term strategies (Borrus 1988; Warshofsky 1989). A major source of this capital advantage was the vertical and horizontal integration of the semiconductor divisions within large electronics firms, which were in turn linked to banks belonging to a common business group (*keiretsu*). A company's internal electronics division could become a source of cross-subsidies when chip sales were down, and a related bank afforded a ready source of patient funds that most stand-alone US chip companies could not match (Okimoto and Nishi 1994).

The main product on which the Japanese firms rose to market dominance was dynamic random-access memory (DRAM), the memory chips used in computer hardware, a technology area where the Japanese government was anxious to establish national autonomy. In the 1970s, IBM's internally produced memory chips were a key source of advantage for its successful System/370 mainframe computer system, with which Japanese companies such as Fujitsu and Hitachi were competing (Fransman 1995).

DRAM was considered strategic because it was process-driven and a perfect vehicle to learn about each new generation of process technology. Every two to three years a process using a finer linewidth would enable companies to fit the most memory cells into the smallest chip size, which minimizes unit production cost. Because of the high investment costs for both process and product development, market leadership in memory chips required high capital expenditures. This could be justified by the large demand for memories, which accounted for 15 to 20 percent of semiconductor revenues during the late 1980s. The long production runs of a single design permitted learning about the process, which raised yield (the percentage of defect-free die on a wafer) and further lowered unit cost. The process and the lessons learned could then be applied to other types of chips, such as microprocessors. Because of the importance of volume production to take advantage of economies of scale, the ability to ramp quickly to high volumes with high yield for the latest-generation memory chip provided competitive advantage through lower costs.

Japanese companies excelled in the process-oriented business of high-volume memory production. In the industry's early years, getting a process to work at minimum acceptable yield was a sufficient foundation for competitive advantage, but as the DRAM market matured, fab efficiency in terms of yield and cycle time became critical (Burgelman 1994). A 1987 report by a US Defense Science Board task force reported that of the twenty-five major semiconductor products and processes considered, Japanese companies were better in twelve and US companies were better in five, with rough parity in five more.[2] By the mid-1980s, the best Japanese producers were achieving yields of 70 to 80 percent, while the best US firms were in the 50 to 60 percent range (Prestowitz 1988). The reliability of Japanese memory chips was also higher (ibid.). US memory producers saw their market share fall from 75 percent in 1980 to just over 25 percent in 1986, while that of Japanese producers rose from 24 to 65 percent during the same period (Borrus 1988, fig. 7.1).

The shift in the memory market was reflected in the industry as a whole. Table 1.1 shows the top ten firms in the overall semiconductor industry for 1980 and 1990, a decade during which industry revenue expanded almost fivefold. The rise of Japanese producers (shaded gray) in the 1980s, mirrored in the relative fall of US producers, can be seen clearly. In 1980, Texas Instruments (TI) was the leader with 14 percent of the market, and the six US companies in the top ten accounted for 43 percent. In 1990, TI's share, despite a doubling of its annual revenue, had fallen to sixth place, and two of the top five chip suppliers (NEC and Toshiba) were Japanese, with the five Japanese companies in the top ten accounting for 31 percent, while the four US companies totaled only 23 percent. This changing of the guard was a great source of

Table 1.1
Change in industry leadership, 1980 to 2000

1980		1990		2000	
Total market $9.4 billion		Total market $44.6 billion		Total market $197.1 billion	
Texas Instruments	14%	NEC (Japan)	8%	Intel	15%
National Semi.	7%	Toshiba (Japan)	7%	Samsung (Korea)	5%
Motorola	7%	Intel	7%	NEC (Japan)	5%
Philips (Europe)	7%	Hitachi (Japan)	7%	Texas Instruments	5%
Intel	6%	Motorola	6%	Toshiba (Japan)	4%
NEC (Japan)	6%	Texas Instruments	6%	STMicro. (Europe)	4%
Fairchild	5%	Fujitsu (Japan)	5%	Motorola	4%
Hitachi (Japan)	4%	Mitsubishi (Japan)	4%	Micron	3%
Toshiba (Japan)	4%	National Semi.	4%	Hyundai (Korea)	3%
Mostek	4%	Philips (Europe)	3%	Hitachi (Japan)	3%

Source: Market research data.
Note: Companies without a geographic designation are US-based companies.

concern in the United States. Some industry observers feared the shift would be permanent: "Japanese producers' dominance of the world chip market threatens to be more or less assured, *even if US producers were to recapture parity in process R&D and manufacturing*" (Borrus 1988, p. 7; italics in original). Government pronouncements, as typified by the Commerce Secretary's quote at the beginning of the chapter, were also grave.

1.2 The US Response

US companies had multiple responses to the challenge from Japan, including improvements in manufacturing quality, politically oriented strategies toward Japan, and strategic shifts in their product mix. The government played an important role with both macroeconomic and industry-level policies.

US firms worked hard to raise the yield of their factories and the quality of their output. One of the best-known examples is Motorola's Six Sigma quality program, which was developed starting in the early 1980s and has since been adopted in a wide range of industries.[3] The "sigma" refers to a statistic that measures the share of output that is acceptable, and "six sigma" corresponds to a defect rate of 3.4 parts per million. The tools involved, such as statistical process control, already existed, but Six Sigma marshaled them in a long-term effort that emphasized employee involvement in preventing, rather than detecting, problems.

US chip firms also overcame their aversion to "not invented here" know-how. Many companies participated in benchmarking efforts such as UC Berkeley's Competitive Semiconductor Manufacturing (CSM) program (http://microlab.berkeley.edu/csm/), which launched a comparative study in 1992 that made detailed analyses of operations at more than 30 fabs worldwide to develop a set of performance-tied best practices based on comparative benchmarks.

Meanwhile the industry pursued political strategies to improve their competitive position vis-à-vis Japan in concert with the US government. In 1977, five leading US chip producers joined together to form the Semiconductor Industry Association, which gave the industry a more unified voice for lobbying the federal government. In 1985, the Semiconductor Industry Association (SIA) filed an unfair trading petition with the US government, claiming that Japan was continuing to protect its market in violation of intergovernment semiconductor agreements that had been reached in 1982 and 1983. This, along with dumping actions on specific types of chips, helped pressure Japan to agree in 1986 to even more drastic measures, although US penetration of the Japan market remained limited (Prestowitz, op. cit.). In 1987, the US imposed penalties of $300 million on Japanese imports to bring further pressure for the enforcement of existing agreements. The Japanese chipmakers found the US pressure very strong, particularly under the first Semiconductor Trade Agreement, which lasted until 1991 (Chuma and Hashimoto 2008).

On the macroeconomic level, US government policy to lower the value of the dollar was also helpful. The 1985 Plaza Accord devalued the dollar relative to the yen, and over the following two years, coordinated central bank action helped lower the exchange value of the dollar against the yen by 51 percent.

On the home front, the US government relaxed the antitrust laws affecting interfirm cooperation and provided half the $200 million annual budget for a research consortium of fourteen US chip companies called SEMATECH, which was formed in 1987 (Ham et al. 1998). The general goal was to pool resources for the improvement of manufacturing technology.

After an uneven start, SEMATECH eventually made strides by getting US semiconductor manufacturers and their specialized equipment suppliers working together on ways to improve US chip manufacturing (Grindley et al. 1994). The model of horizontal and vertical cooperation was based on the earlier successful collaboration that was believed to have contributed to the Japanese success in the chip industry (Fransman 1990). Major government support ended in 1996, and SEMATECH continued forward as a privately funded consortium that has continued to play an important role in equipment innovation and fab productivity.

US firms also responded to the Japanese crisis by adjusting their product mix, most notably by exiting the DRAM market, where the determined investment of the Japanese combined with a dip in demand in 1986 led to a situation of severe overcapacity. As US trade negotiator Clyde Prestowitz put it: "the US semiconductor industry was staring death in the face. It reported losses of nearly $2 billion for 1985 and 1986, while twenty-five thousand people lost their jobs. The Japanese companies lost twice as much money . . . but . . . in a contest of deep pockets theirs were deeper" (1988, p. 55).

Facing red ink and a dismal outlook in memory chips, Intel, which had been one of the first companies to market memory chips, exited in 1986 in order to concentrate on microprocessors, a category it had also pioneered. Around the same time, nine of the eleven US-based producers of high-volume memory chips also exited the memory market (Young 1992). An effort by a group of computer and chip companies to launch a jointly owned memory manufacturer to be called US Memories eventually failed to raise enough funding and was abandoned in 1990. But the firms that remained, such as IBM and Intel, were able to close the technology gap in memory with the Japanese leaders (Iansiti and West 1999).

Intel's microprocessor had been selected for the first IBM PC in 1981. Through a series of strategic moves, including defending its intellectual property and pushing its process technology to the industry forefront, Intel created a competitive wedge between itself and rivals, Intel shored up its position in the microprocessor market during the 1980s by ending its "second-sourcing" agreements with other chip firms, which closed a door to competition. Although Intel's Japanese rivals, such as Fujitsu and NEC, viewed this practice as unfair, they did not push their government to lobby the US government for more competitive practices because the Japanese government was already mired in demands by the US government to open Japanese electronics markets and revalue the yen.[4]

In a series of court cases against one of its licensees, Japan's NEC, Intel established the principal that microcode (the software embedded in a chip's design) is copyrightable, as well as the idea that Intel would vigorously contest challenges to its intellectual property (Afuah 1999). To further separate itself from competitors, Intel sped up its product development cycle and, in 1991, launched an unorthodox branding campaign ("Intel Inside") for its processors.

Intel carved out a quasi-monopoly that grew to account for nearly a fifth of the semiconductor industry's sales at its peak in the late 1990s. In 1999, Intel captured 82 percent of the microprocessor market, even counting non-x86 architecture chips.[5] This is well above the level of market share at which the US Department of Justice considers the industry to be "concentrated."[6]

As US companies were leaving the memory market, dozens of US startups were founded to take advantage of advances in design automation software for designing "application-specific integrated circuits" (ASICs). ASICs, often designed for a particular customer, did not benefit from the cost-reducing volume manufacturing techniques mastered by Japanese firms, but they were able to command a higher profit margin because of their significant advantages, such as reduced unit cost and greater reliability compared with the less-integrated set of chips that would be needed to provide the same functionality.

ASIC entrants from the early 1980s, including LSI Logic and VLSI Technology, generated billions of dollars in revenue and owned their own factories. Beginning in the mid-1980s, a second wave of ASIC start-ups that outsourced production became an important—and US-centric—part of the industry. These "fabless" chip firms will be discussed in the next chapter.

A few US memory producers stayed in the market for most of the 1990s Motorola announced its departure in 1997, and Texas Instruments sold its global DRAM operation to Micron in 1998 in order to concentrate its efforts on building a business in digital signal processors (DSPs), a key component in many of the latest electronics products, from cell phones to anti-lock brakes. IBM, which was a large-scale DRAM producer for its internal needs, announced its exit from DRAM manufacture in 1999 as it ramped up its business in custom logic chips.[7]

The sole US memory survivor, Micron Technology, carved out its niche by using aggressive design methods to trim costs rather than copying the Japanese strategy of relentlessly improving manufacturing technology (Afuah 1999). In addition Micron successfully sued its Japanese rivals in 1985 for violations of US antitrust and antidumping laws. Micron has periodically tried to diversify, first into system-level products like PCs in the 1990s, then into specialized chips like CMOS image sensors for cameras in the 2000s, but memory chips remain its primary line of business.

1.3 The Table Turns

These measures taken by US firms and the government contributed to another dramatic reversal of fortunes, this time with the US industry overtaking its Japanese rivals. Figure 1.1 shows the rise of Japan's global chip market share during the 1980s followed by a steady decline during the 1990s, which caused alarm in Japan.

The increase in the US industry's share largely reflected the growth of one firm—Intel. As shown by the dotted line in figure 1.1, the US share excluding Intel has hovered around 30 percent, only slightly above the Japanese share since 1988.

Table 1.1 shows the top ten firms by revenue in 2000. Intel's share had grown to three times that of the second-ranked firm, Korea's Samsung. Only three Japanese firms were listed, with a combined share of 12 percent. Table 1.2 shows the top ten firms in 2007. Intel occupied the leadership position at 12 percent, but Samsung's share grew to 8 percent.

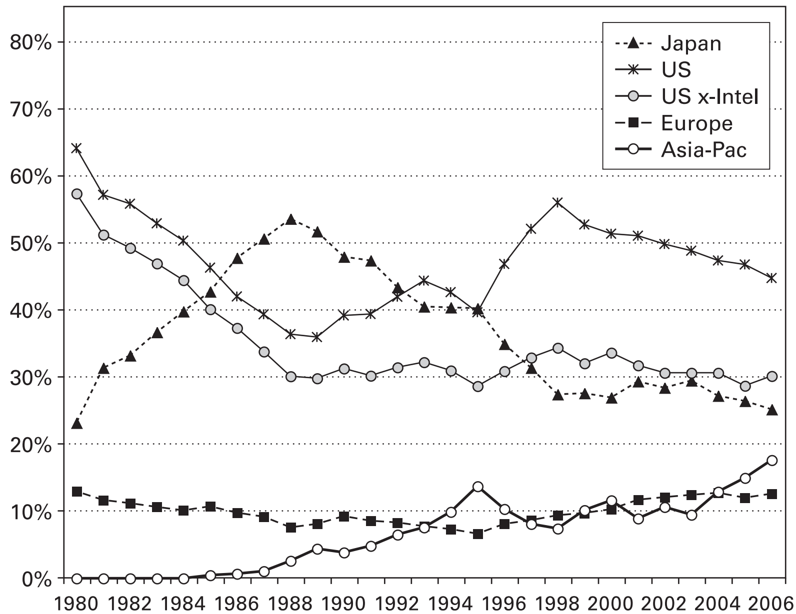

Figure 1.1
Regional shares of semiconductor sales, 1980 to 2006. Source: Authors' calculation using top forty firm data from market research sources. The top forty accounted for 80 to 90 percent of total semiconductor sales during the period.

Samsung Electronics is part of a Korean business group with industrial activities in nontechnology areas such as textiles and sugar. In the 1970s it entered into the semiconductor industry with government inducements in the form of training programs and subsidized credit (Mathews and Cho 2000). Samsung eventually decided to focus on producing DRAM because it's a high volume, standardized product for which the manufacturing skill that it had already developed for complex products such as television tubes was paramount (Hong 1992). Although it initially had to license dated technology from US and Japanese competitors in the early 1980s, it gradually built up its internal technology resources and became the first to demonstrate a working prototype 256-Megabit DRAM in 1994 (Kim 1997). Samsung's leadership of the memory market is also built on a foundation of manufacturing excellence, such as the shortest time required for a wafer to move through the entire fabrication process.[8]

Table 1.2
Top ten semiconductor vendors by revenue, 2007

2007 rank	Company	2007 revenue (US$ millions)	Market share
1	Intel	$33,800	12.3%
2	Samsung (Korea)	$20,464	7.5%
3	Toshiba (Japan)	$11,820	4.3%
4	Texas Instruments	$11,768	4.3%
5	Infineon[a] (Europe)	$10,194	3.7%
6	STMicro. (Europe)	$9,966	3.6%
7	Hynix[b] (Korea)	$9,100	3.3%
8	Renesas (Japan)	$8,001	2.9%
9	AMD	$5,884	2.2%
10	NXP[c] (Europe)	$5,869	2.1%
	Others	$147,045	53.7%
	Total market	$273,911	100.0%

Source: "Worldwide semiconductor revenue increased 4 percent in 2007, according to final results by Gartner," Gartner Press Release, March 31, 2008.
Note: Companies without a geographic designation are US based. If Taiwan foundry TSMC were included, which would be double counting, their $9,828M revenue would put them in seventh place.
a. Infineon's share also reflects sales of its majority-owned memory-chip spin-off Qimonda.
b. Hynix was formerly Hyundai Semiconductor.
c. NXP was formerly Philips' semiconductor division.

In the 2007 top ten, the United States is represented by three firms with a combined share of about 19 percent. Meanwhile Japan's presence among the top ten continued to decline to two companies with 7 percent combined share. The 8th-ranked firm in 2007, Renesas, is a joint venture that took over the logic and flash memory chip divisions of Hitachi and Mitsubishi in 2003.

The reversal of fortunes between the United States and Japan had as much to do with events in Asia as with those in the United States. Even in high-volume memory chips, the top spot was taken from Japanese firms by a Korean producer, Samsung, which followed a relentless investment strategy out of the Japanese playbook in its pursuit of market share. By the mid-1990s, after a decade of effort, it captured the top spot in memory production, which it has held ever since. Another Korean producer, Hyundai Semiconductor (now called Hynix) and, later, Taiwanese producers such as Nanya, Powerchip, and ProMOS grew in importance. The emergence of Korea and Taiwan in the overall industry can be seen in the "Asia–Pacific" line in figure 1.1

Table 1.3 shows the top eight producers of DRAM in 2007. Outside of Taiwan and Korea, the only remaining major DRAM producers are Qimonda in Europe, Micron in the United States, and Elpida in Japan. Qimonda was spun off in 2006 by Infineon, a semiconductor company that was itself spun off from Germany's Siemens in 1999, but is not yet independent as of 2008. Elpida was created in 2000 from the DRAM divisions of Hitachi, NEC, and, later, Mitsubishi. Japan's other leading memory producer, Toshiba, has switched most of its memory efforts to flash chips, which are more expensive but are used in mobile devices because they retain their data even after their power source is switched off.

As mentioned above, DRAM was considered of strategic importance in the 1980s. However, the current domination of the DRAM market by companies based outside the United States, Europe, and Japan is no longer seen as the crisis it would have been twenty years ago. The main reason is that DRAM was knocked off its technology-driver throne by other types of chips that also permit high-volume runs of a single design, with their related learning benefits. In the United States, Intel uses its newest process on its processors, while Texas Instruments uses its

Table 1.3
Worldwide DRAM market shares by revenue, 2007

Rank	Company	Headquarters country	2007 sales ($US millions)	Growth 2006–2007	Market share
1	Samsung	South Korea	$8,699	–11.5%	27.7%
2	Hynix	South Korea	$6,682	18.4%	21.3%
3	Qimonda	Germany	$3,965	–26.2%	12.6%
4	Elpida	Japan	$3,758	7.7%	12.0%
5	Micron	United States	$3,185	–13.8%	10.1%
6	Nanya	Taiwan	$1,479	–29.9%	4.7%
7	Powerchip	Taiwan	$1,229	–16.9%	3.9%
8	ProMOS	Taiwan	$1,071	–26.7%	3.4%
	Others	—	$1,352	12.0%	4.3%
	Total		$31,420	–8.4%	100.0%

Source: Sales, growth, and share data are Gartner estimates reported in Mark LaPedus, "Elpida, Hynix gain in DRAM rankings," *EE Times*, February 4, 2008.

DSP-based cell phone baseband chips as its high-volume learning device. Flash memory, which used to lag by three years, has become the driver at Samsung, the leading DRAM company.[9] Early in the 2000s Samsung foresaw the enormous potential demand for solid-state data storage and began doubling flash density every year, well ahead of the pace predicted by Moore's Law.

DRAM, which has characteristics of a commodity because of the interchangeability of products among vendors, is a particularly cyclical chip market as swings in capacity and demand are often poorly synchronized. During periods of excess capacity, prices fall, sometimes below manufacturing cost for the least efficient producers. The end of 2007 saw the beginning of such a period. The relatively small Taiwanese producers are most at risk because of their reliance on foreign technology partners and a heavy debt burden.[10] The Taiwanese memory firms appear unlikely to emerge in their present form from the deepening recession, with some kind of restructuring expected as part of a new government partnership with Elpida.[11]

1.4 How Japan Stumbled

Beyond steps taken by companies in the United States and the rest of Asia, the relative decline of Japan's chip industry owes a lot to circumstances in Japan.[12] These include a deterioration of the investment climate, an overemphasis on quality, and an overdependence on the domestic market. Another factor, Japan's weak environment for start-up ventures, is addressed in the following section.

One of Japan's biggest impediments to continued market leadership was a decline in investment in new factories brought on by the bursting of Japan's asset bubble in the early 1990s.[13] The end of a real estate bubble led to a credit crunch, and companies found it more expensive and harder to raise funds through issuing bonds or stocks. Already burdened by high debt-to-equity ratios, Japanese firms reduced their capital equipment spending in 1992. Meanwhile Korean firms raised theirs.

Although factors like chip size and cost also influence DRAM market share, steady renewal of leading-edge production capacity is the bare minimum for maintaining or raising market share. The global share of capital expenditures shadows the country shifts in memory leadership (table 1.4). Japan's share of capital expenditures by chip firms rose from 29 percent in 1980 to 50 percent in 1990, and then fell to only 25 percent by 1997. Meanwhile the share of US firms fell from 60 percent in 1980 to 30 percent in 1990, and then recovered only slightly. Meanwhile the "rest of world" category, primarily Korea, starts from zero in 1980, and grows to 33 percent in 1997.

Ironically, the emphasis on quality and reliability that brought Japanese firms to the top of the memory chip industry was part of their undoing, as the primary application markets for memory shifted from mainframes, where long-term reliability was highly valued, to personal computers and consumer products with more limited life spans (Cole and Matsumiya 2007). Japanese DRAM engineers continued to use costly, customized equipment to produce chips that exceeded expectations when

Table 1.4
Capital spending by semiconductor companies, share of world total, selected years

Region	1980	1985	1990	1997
United States	60.4%	35.5%	29.8%	33.0%
Japan	28.9%	46.7%	50.0%	25.0%
Europe	10.7%	8.3%	9.9%	9.0%
Rest of world	0.0%	9.4%	10.3%	33.0%
Total	100.0%	100.0%	100.0%	100.0%

Source: Macher et al. (1999, fig. 4); data supplied by author.
Note: Columns may not total precisely, due to rounding.

most other chip producers were pursuing more standardized solutions (Yunogami 2006).

Japan was also undone by the domestic focus of its chip firms, most of which were part of large conglomerates making a range of electronic and electrical systems. This was a strength when it came to promoting sales opportunities among business group networks, and Japanese companies were able to rely on high prices in Japan to subsidize price-based competition overseas (Prestowitz, op. cit.). But this strength became a major weakness when the Japanese economy, which had roared ahead at more than 3 percent per year in the 1980s, slid into a decade of much slower growth in the 1990s coupled with price deflation.

All the leading Japanese chip producers of the 1990s were vertically integrated with systems divisions. Although Japanese systems companies were strong in mainframe computers, they were less active in personal computers, the major global growth market of the 1990s. The Japanese market was relatively slow to adopt the PC platform, which partly reflected the difficulty of inputting Japanese characters. In 1995 Japan had roughly one-fifth the PCs per capita of the United States.[14] Instead of general-purpose PCs, Japanese business users had favored specialized equipment like dedicated word processors.

The idiosyncrasies of the domestic market had implications for memory chips as well.[15] Although DRAM chips are often referred to as a

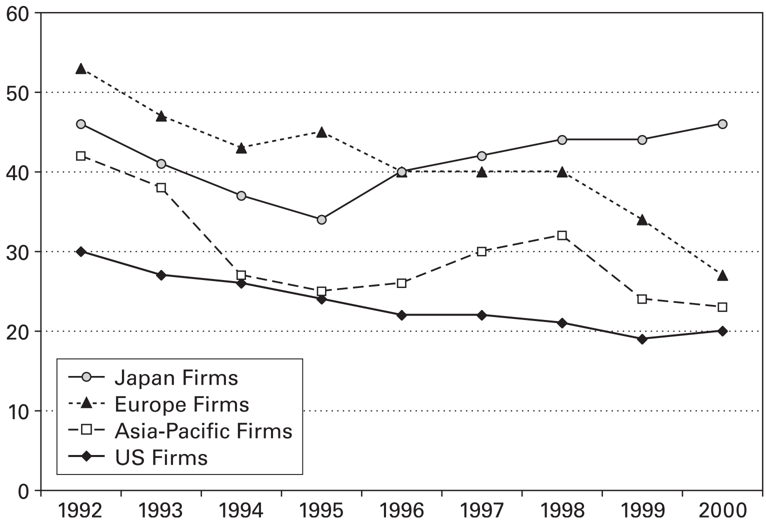

Figure 1.2
Home substitution index for semiconductor sales, 1992 to 2000 (authors' calculation; see appendix for details).

commodity product, there are subtle but important differences of configuration (e.g., number of bits per storage unit, power supply) that would require significant engineering effort to redesign. The DRAM requirements of Japan's consumer electronics makers, which were foremost for their captive chip divisions, were incompatible with those of PC makers in the rest of the world.

Japan has been referred to as a Galapogos market—a market that is vibrant with ideas and original innovation, but this innovation doesn't spread to global markets became Japan is isolated from the rest of the world, which develops in a different way.[16] We think that this describes what has happened in many semiconductors and consumer electronics markets.

To explore Japan chipmakers' dependence on the domestic market and relative isolation from the global market, we constructed a "home substitution index" that shows (figure 1.2) the excess of semiconductor sales to the home market above the home market's share of total global sales (see the chapter appendix for details). For Europe, Asia–Pacific (i.e., Taiwan and Korea) and the United States, the home substitution index ends lower in 2000 than it begins in 1992. In sharp contrast, Japan's reliance on chip sales within Japan starts high and increases during the late 1990s even though Japan's chip consumption declined as a share of the world market, from 32 percent in 1992 to 23 percent in 2000. The global share of Japan's market peaked in 1988 at 40 percent.[17] The US market went from 30.8 percent of world chip consumption to 31.3 percent over the same period.

The dip in Japan's Home Substitution Index (HSI) in the mid-1990s is driven by a boom in the memory market that allowed Japanese chip makers to expand overseas. As Japan's memory market share declined during the later years of the 1990s, Japanese chip makers lost share faster overseas than at home. Japan's HSI for non-memory chips alone was relatively flat, falling slightly from 57 in 1992 to 51 in 2000.

Table 1.5, which shows the regional breakdown of sales by the top ten chip companies in 2005, provides an updated view of Japan's home-market dependence. While most of the non-Japanese companies earn about half of their revenues in "Asia–Pacific" because of the importance of Taiwan and China for electronics manufacturing, the three Japanese firms earned between 57 and 63 percent of their revenues from sales to Japanese customers. Meanwhile the Japan market declined even further in terms of world consumption. By 2005 Japan's market size had fallen to 19 percent (and the United States to 18 percent) as Asia–Pacific (mostly China) grew to 45 percent of the world market.

Japan's largest chip companies have been undertaking organizational restructuring in response to their decline. Hitachi, which was almost out of the top ten by 2000 (table 1.1), divided its chip manufacturing into two joint ventures: a memory venture with NEC called Elpida and a separate venture for logic and flash with Mitsubishi called Renesas, which was the eighth-ranked chip firm in 2007. Among Japan's other major chip producers, Fujitsu put its flash operations into a joint venture called Spansion with US firm AMD, and Sony shifted the manufacturing plants for the processors in its Playstation game consoles into a minority-owned joint venture to be controlled by its development partner, Toshiba. The consolidations and alliances have allowed the newly created firms to achieve greater focus and better scale economies.

Table 1.5
Top ten chip companies' sales by region, 2005 (percentage of global semiconductor revenue)

2005 rank	Company	Americas	Europe–Middle East	Japan	Asia–Pacific
1	Intel	19.6%	21.0%	9.5%	49.9%
2	Samsung (Korea)	28.7%	19.9%	16.4%	35.0%
3	Texas Instruments	14.2%	19.6%	15.3%	50.9%
4	Toshiba (Japan)	6.2%	4.3%	62.7%	26.8%
5	STMicro. (Europe)	16.5%	33.5%	3.4%	46.6%
6	Infineon (Europe)	24.6%	37.7%	4.8%	32.9%
7	Renesas (Japan)	6.2%	9.3%	58.9%	25.6%
8	NEC (Japan)	12.3%	12.2%	56.5%	19.1%
9	Philips (Europe)	9.5%	25.2%	4.3%	61.1%
10	Freescale	26.6%	20.4%	5.1%	48.0%
	Top ten companies	18.0%	20.5%	19.9%	41.6%
	Others	17.5%	12.0%	23.3%	47.2%
	All companies	17.7%	16.1%	21.6%	44.5%

Source: iSuppli, as reported in "iSuppli: Asia Pacific shaped fortunes of key chip suppliers in 2005," *DigiTimes.com*, May 11, 2006.
Note: Companies without a geographic designation are US-based.

Beyond memory, Japanese chip makers clung to broad portfolios of chips while producers elsewhere were pursuing specialization, as exemplified by the processor-centric strategies of Intel and Texas Instruments. Medium-size US chip companies account for about half the firms in the global top fifty. A great many of the US firms are relatively young, having been founded since 1980, and specialize in specific types of analog or digital-logic chips. One area where the United States has achieved global competitive advantage has been with fabless companies, where Japan continues to lag.

1.5 United States and Japan: Start-ups a Defining Difference[18]

Based on the US experience, start-ups are an important way for an economy to exploit new opportunities, but Japan's economy is relatively inhospitable to high-tech start-up ventures. In the fiscal year ending March 2004, Japan had well over fifty companies with electronics revenues of more than US$1 billion, but none of them were established more recently than 1968.[19] The most recently established semiconductor firm among them was Rohm (1958). By contrast, the United States is home to many electronics companies that are much younger and have grown to considerable size, such as Dell (1984), Cisco Systems (1984), and Solectron (1977). Among the top twenty US semiconductor companies in 2004, all with revenue greater than US$1 billion, three were founded in the 1960s (including Intel), six in the 1980s, and two (Nvidia and Broadcom) in the 1990s.

The importance of smaller companies in the innovation process in the United States is highlighted by the fact that National Science Foundation data show companies with less than 250 employees account for 9 percent of manufacturing R&D spending, and have an R&D-to-sales ratio of 7.5 percent.[20] Small and medium enterprises play a more limited role in manufacturing and R&D in Japan, where firms with up to 300 employees account for only 4 percent of manufacturing R&D spending and have an R&D-to-sales ratio of 2.2 percent.[21]

In both the United States and Japan, major semiconductor and electronics producers undertake a great deal of R&D, but less than half of the ideas generated internally are developed further.[22] Start-ups can be an important vehicle for exploiting ideas that industry leaders do not pursue. With low overhead and rapid decision making, start-ups can develop new technology and products faster and cheaper than large companies can.

The primary business model for semiconductor start-ups is the fabless model, in which the company designs and markets its own chips but outsources the manufacturing to another company, most frequently a "foundry" that specializes in manufacturing chips for others (Crisis 2). According to the Fabless Semiconductor Association's report on publicly traded fabless companies in 2005, 84 US companies accounted for 64 percent of global fabless revenues.[23] The second-highest concentration of fabless companies was in Taiwan, with 62 companies and 17 percent of revenues. Fabless companies were scarce in Japan, with three listed companies (MegaChips, RealVision, and THine Electronics) accounting for just over 1 percent of global fabless revenues.

Whittaker's study of Japanese entrepreneurs describes them as "lifework entrepreneurs" whose companies are typically oriented toward the domestic economy, focused on developing technology, and limited in finding first customers or selling business assets (Whittaker 2009). He sees Japanese entrepreneurship as both shaped by and limited by the nature of markets as well as social and cultural factors.

A high-level and comprehensive national report[24] on the state of start-ups reflects Japan's concerns that the country is losing out, especially to the United States, on developing innovation in high-tech industries because of lack of a supportive environment for start-ups, especially in relations with large Japanese enterprises and in operating in domestic labor and financial markets. Our 2004 to 2006 fieldwork at start-ups in Tokyo, Yokohama, Kyushu, and Osaka was consistent with this report. We found that Japanese start-ups face four major difficulties:

1. Acquiring management and marketing skills, since there are a limited number of executives with start-up experience.
2. Finding customers, since large Japanese companies prefer established suppliers.
3. Recruiting engineers, who don't want to lose the status and security provided by a large company.
4. Securing venture capital financing, because the total amount of Japanese venture capital investment was about 3.6 percent of the US amount in 2006.[25]

Japanese start-ups take several forms, and they can be characterized by their independence from, or their ties to, large companies.

The self-funded *independent start-up* model is used by many young Japanese companies in the electronics industry. Initial funding is provided by the founders, who sell services to generate cash flow while a new product is being developed. For example, start-up semiconductor firms in Japan often sell chip design services while developing their own chip. This was the model followed by MegaChips, a fabless semiconductor company founded in 1990 and listed on the Tokyo Stock Exchange in 2000.

Although this model can succeed, it is a slow path to innovation. Independent start-ups suffer from inadequate initial funding and from lack of access to large Japanese companies as customers. The services business, which has limited growth potential, requires as much as 80 percent of the managers' and engineers' time, which slows down the development of an innovative product.

An important but rare variant is the *Silicon Valley model* where the start-up adopts a high-risk, high-return strategy of commercializing innovative technology with funding from venture capitalists instead of using the cash flow from services. This model, pursued by visionary firms like Internet companies Rakuten and Google, is slowly becoming more common in Japan. However, most venture-funded start-ups in Japan are less ambitious than those in the United States. Companies like Sony and Matsushita operate corporate venture capital subsidiaries, but so far most of their investments are outside Japan. Silicon Valley's venture capital model, which targets opportunities for high, rapid growth with a low success rate, is not congruent with Japanese economic institutions and culture where failure carries a heavy penalty, such as the inability to obtain bank financing for a new venture for ten years after a business failure.

A common method of creating new companies in Japan is for a large company to assign a developed technology to a wholly owned *corporate division or subsidiary* that remains under corporate control. We consider these divisions or wholly owned spin-offs to be paths to commercialization rather than innovation because they typically involve a late stage of product development, and employees are still under the large company's umbrella and protected from failure. The employees are also prevented from sharing in high returns from the innovation in the event of a success. An example of this type of company is Hitachi's Mu Solutions, which was set up as an in-house (*shanai*) venture company (i.e., fully owned but with separate management team) to commercialize wireless data tags. After Mu Solutions became a supplier to a large company, Hitachi returned the venture back to Hitachi to facilitate total systems integration.[26]

The *independent spin-out* model, which represents a more autonomous type of corporate spin-out, is rare in Japan. When a parent company has a technology that it chooses not to develop, the engineers who worked on the technology leave to start a new company that receives an exclusive technology license and only partial funding from the parent company. An example is Fab Solutions, which markets an advanced system for process control in semiconductor manufacturing. Four engineers from NEC were allowed to take the business private in 2002. They obtained two rounds of venture funding and were included in a 2004 list of "Top Emerging Start-ups"[27] but appear to have gone out of business.

The *cooperative venture* involves an independent start-up that enters a strategic alliance with a larger company that provides up-front resources in return for a share of the licensing fees or a share of output. The large company will usually be part of the venture company's supply chain (e.g., an equipment supplier or potential customer). This relationship overcomes some of the problems facing venture companies in Japan. This model has the advantage of providing better resources and, in the case of downstream cooperation, better access to customers. In the components sector, THine Electronics was founded in 1991 as a joint venture with its customer Samsung Electronics, and the founders were able to buy out Samsung's share in 1997. A younger semiconductor start-up, IPFlex, received a minority investment in 2003 from Fujitsu, which provides fabrication services and development assistance.

The Japanese government has already taken important steps to remove regulatory constraints facing start-ups, such as the liberalization of stock options and abolition of minimum capital requirements. Starting a new company in Japan has become easier and less expensive in recent years according to a World Bank ranking.[28] For example, the administrative steps required for registering a new firm fell from eleven in the 2004 report to eight in 2008, but that is still higher than the average of six for the OECD, a group of middle- and high-income countries. The cost of a start-up expressed as a percentage of gross national income per capita has fallen from 10.5 to 7.5 percent, also above the OECD average of 5.1 percent.

The lifetime employment offered to regular employees of large companies coupled with limited participation in the global brain circulation that links the United States and the rest of Asia restrains Japan's labor market mobility. Yet the proportion of the workforce who have lifetime employment in major companies has fallen (Nakata and Miyazaki 2007), and younger Japanese who entered the labor market to diminished opportunities during Japan's long recession are more mobile and more global in their outlook. We expect that the hold of lifetime employment will continue to weaken and mobility will increase over time, which may prove to be an important step in building a foundation for start-ups in Japan.

1.6 Lessons and Conclusions

Shifting global competitive advantage in the 1980s and 1990s created an atmosphere of crisis in the United States in the 1980s and then in Japan in the 1990s, and drove changes in both countries. The key response in the United States was the major change in product mix from memory toward processors and custom logic. This radical repositioning was led by Intel's microprocessor powerhouse, and was supported by a wide range of companies exploiting new technological opportunities. Japan's response in the 1990s was constrained by her weak domestic economy, and her semiconductor industry underinvested in capacity.

One of the primary lessons of the global leadership crisis is that in a rapidly evolving industry like semiconductors, national competitive advantage is often fleeting. Japan's global competitive advantage evaporated with strategic responses by rivals and Japan's own response to a weak domestic economy. This echoed the way that Japan's initial rise highlighted the weaknesses of the US market leaders. American chip companies are again riding high, but as we will see in the rest of this book, any of a number of ongoing crises could unseat them as recent entrants in Asia compete for market share and global competitive advantage.

The struggle for global advantage during the 1980s and 1990s brought considerable benefits to the world's consumers, particularly businesses, in the form of computer platforms with steadily improving performance at steady prices. Of course workers' fortunes reflect the fortunes of their employers and industry, and semiconductor workers suffered from the swings in employment and profits. In Crisis 6 we describe how the weakened market position of US firms resulted in an erosion of employment security and firm-based retraining and an increase of labor mobility.

For governments, the years of US–Japan rivalry established the reduced scope for government intervention in an established industry. In the 1970s a range of policy tools such as tariffs and subsidies were available to the Japanese government in its effort to overtake US chip firms, and international trade agreements forced these to be dropped once Japan's industry was established. The direct policy tools of the past have been sidelined by various agreements under the World Trade Organization (WTO), although developing countries like China are still able to provide subsidies to push their infant industry along.

Nevertheless, governments still have important roles to play in managing their exchange rates, financial markets, and domestic economies, all of which can have a major impact on the semiconductor industry. Governments also fund WTO-compliant precompetitive joint research programs in Europe, Japan, and the United States.

Government can also play a more direct role. The Franco–Italian joint venture STMicroelectronics, which has been a top ten chip firm since the mid-1990s, was majority-owned by French and Italian government entities until 1999 and has benefited from regular participation in EU programs for microelectronics research, so it would be an exaggeration to say it was fully exposed to the free market. Direct intervention still takes place to varying degrees. As the global economic recession spread in 2008, the Taiwan government proposed loan relief for its memory chip firms, and a Chinese government-connected telecommunications firm, Datang, made a major investment in China's leading, but loss-making, chip manufacturer, SMIC.[29] We expect to see more government intervention to help faltering firms worldwide, as companies shift their strategies toward survival rather than global competitive advantage, to which we return in Crisis 7.

The industry has always faced large business cycle swings. However, the challenges of these large demand swings have become more severe because of the rapidly rising fixed costs for manufacturing and design, to which we turn in the next two chapters.

Appendix

The Home Substitution Index (HSI) in figure 1.2 is a statistic that allows us to see whether firms from a chip-producing region realize a greater share of revenue in their "home" (own region) market than we would expect given the size of that market. The measure is standardized for the size of the home market so that the results are comparable across regions.

The HSI is calculated using the following formula:

$$\text{HSI} = \frac{[(\text{\% of Sales in ``Home'' Region}) - (\text{``Home'' Market as \% of World Market})]}{\text{Foreign Markets as \% of World Market}} \times 100.$$

The HSI shows to what extent the "excess" sales to the home market (i.e., sales above home's market size) "replace" sales to foreign markets. Given that the share of "home" sales by chip firms in each region was larger than that regional market's share of world sales, the relevant range of the index is from 0 to 100. The lower is the HSI, the more global are the sales distribution of home-based firms. At zero, the share of sales to the home market matches the market's relative size. If true for all regions, this would represent a state of perfect, frictionless globalization. At 100, sales to the home market replace 100 percent of the sales to foreign markets. If true for all regions, the world is broken into isolated regional blocs.

In 1992 the HSI shows that US companies replaced 30 percent of the foreign sales that would have been predicted if the industry were perfectly globalized with sales in the Americas. In other words, in 1992 US companies' sales to foreign markets were 70 percent of what would be expected based on the relative size of the four regional markets.

Companies in all regions except Japan reduced their reliance on home market sales during the 1990s. European, Korean, and Taiwanese firms rapidly became more global in sales as their HSI converged toward the US low value of 20 in 2000.