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Crisis and Adaptation in East Asian Innovation Systems: Semiconductors in Taiwan and South Korea

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ABSTRACT

In recent decades, both South Korea and Taiwan have made remarkable leaps in the development and production of semiconductors--the core element in burgeoning global telecommunications, computer, and computer equipment industries. Although many aspects of their sectoral industrial strategies have differed, both countries are now moving aggressively to adapt their semiconductor industries to turbulent global markets. In the wake of a severe regional financial crisis that began in 1997, this case study compares and contrasts continuing processes of adaptation among primary semiconductor manufacturers in the two countries. The crisis had observable effects, especially in Korea, but it was not deep enough to force fundamental adjustments in either country. In the early days of the industry in both places, a sense of vulnerability—the need to come from behind—gave rise to quite different corporate structures and attendant strategies. Remarkable differences persist in the ways in which South Korean and Taiwanese semiconductor firms are seeking new advantages in rapidly changing regional and global markets. Strategic change and structural continuity mark the attempt of two relatively small countries to stay competitive in a key industry.

Financial storms buffeted high technology industries in East Asia during the past decade, especially in the 1997-1999 period. Heightened competition in global markets reinforced pressures on both governments and industries to adapt structures and strategies that had sustained remarkable patterns of growth and innovation in previous decades. This study examines continuing processes of adaptation in Korea and Taiwan in the semiconductor industry, an industry that has been critically important in helping to propel national development.[1]

In both Korea and Taiwan, continuity as well as change characterize the contemporary semiconductor industry. Industrial planners and strategists commonly see the industry as providing a bridge between the national manufacturing successes of the past and the science-based industries of the future. The recent experience of the industry across the two countries sheds a unique light on the way in which regional and global pressures for adjustment are interacting with the national legacy of the past. The regional financial crisis that began in 1997, moreover, opened a window through which two contrasting industrial strategies in this key sector came more clearly into view. Beyond the specific decisions of individual firms, this comparative case study explores how two relatively small states are seeking to maintain their room for maneuver in turbulent world markets.

Continuity and change in the Korean and Taiwanese semiconductor industries

The fortunes of the semiconductor industry in Korea and Taiwan have changed quite dramatically during the past few years. The regional financial crisis of the late 1990s hit Korean firms particularly hard, a direct consequence of the vulnerability created by their exceptionally high debt burdens. It changed the strategic context too for the Taiwan industry, even if relatively sturdy financial under-structures provided remarkably successful buffers. But the overall effects of the crisis in both cases are very difficult to separate from the larger simultaneous impact of a dramatic upswing in global markets for semiconductor-related products. The latest boom phase in the so-called "silicon cycle" at once eased pressures for fundamental strategic adjustment and accelerated movement in directions decided upon in earlier days.

In both cases, notable change nevertheless occurred in the mechanisms through which next-generation processes and products are created. In short, the center of gravity in the semiconductor innovation systems in both Korea and Taiwan has now shifted decisively from

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[1] This article, to be published in Business and Politics, is drawn from work undertaken for a larger project on "Innovation and Crisis: Asian Technology in the New Millennium," organized by William W. Keller and Richard J. Samuels at the MIT Center for International Studies. The authors are grateful for advice and assistance from the Semiconductor Research Corporation, Roger Mathus of the Semiconductor Industry Association, Linsu Kim, and the many industry executives and government officials in South Korea and Taiwan who met with us in November 1999. The analysis, interpretations, and conclusions should be imputed to no one but the authors. Pauly's work in the later stages of the project was supported by a grant from the Social Sciences and Humanities Research Council of Canada. For comments on an earlier draft, we are grateful to Peter J. Katzenstein, Richard J. Samuels, Vinod K. Aggarwal, and two anonymous reviewers. Thanks also to Amy Briemer for technical assistance.

government to the private sector. The industries have now matured, and except in particular instances where financial crisis can still lead to direct governmental intervention, each is less dependent on government policy than in the past and more closely attuned to developments in both regional and global markets.

It would be misleading, however, not to emphasize the degree continuity in each case at the level of ideology and deep structure. Industrial trajectories clearly remain influenced by an underlying strategic intent that can only be understood in national terms. Under the rubric of "globalization," a word constantly used by senior executives and government officials in Korea and Taiwan, the clear objective is to defend and build upon the remarkable successes already achieved—for the nation—in the semiconductor and semiconductor-related industries.

The consistent objective in Korea is to continue playing the low-cost-producer game over as large a share of the electronics industry value-chain as possible. The key strategy is to encourage price-driven dependencies on the part of global customers and centrally to control forward and backward technology linkages. The strategy reflects a gamble that underlying technologies, or at least the economics discouraging the rapid diffusion of technologies now at the frontier, are stabilizing. The risks of the strategy are encapsulated therein. Major near-to-medium term breakthroughs—such as leaps in chip miniaturization at the atomic level or through biological processes—could threaten the very existence of the Korean industry. As in the past within Korea itself, although industry spending on R & D is growing, advances at the process level seem most likely. The strategy is risky, but longstanding perceptions among Korean industrial and political leaders of the essential vulnerability of the Korean economy as a whole and the necessity of reducing that vulnerability as quickly as possible appear to make the risks acceptable.

In the Taiwan case, a high degree of continuity in long-term industrial strategy is also striking, although the inherent flexibility of the industry often masks it. The stimulation of basic research promising payoffs in a reasonable period of time, the search for new competitive advantages, and the targeting of promising sectors for the medium-term future remain key governmental missions. Semiconductors are now seen as successfully "launched." Future organizational and product innovation in the sector is viewed quite accurately as industry-led, and it is at that level that remarkable new initiatives are being taken to seize opportunities presented by broader international developments. At the leading edge are Taiwan's foundries, manufacturing companies with relatively open capital bases and low debt-equity ratios, which own key processing technologies but mainly build microchips designed by others. The most important firms are now embarked on an ambitious strategy pinned on alliances with large electronic equipment manufacturers based in Japan and Europe. Alliances also exist with large US companies like Motorola, but the more strategic linkages in the United States appear to be with smaller "chipless" and "fabless" design houses, which do not have the capability themselves of fabricating semiconductors. Such alliances, like the foundry model itself, may plausibly be interpreted as means to an end, and not the end itself. What is that end? No one knows, and there is no centrally controlled master-plan. But the success of this key industry continues to tie directly into perceptions among Taiwan's governing elites concerning the place of Taiwan in a region whose future will likely be profoundly reshaped by the manner and intention with which China inserts itself into an increasingly interdependent global economy.

In their own ways, South Korea and Taiwan made remarkable leaps late in the twentieth century in the development and production of semiconductors--the core element in burgeoning global telecommunications, computer, and computer equipment industries. Although key distinctions remain in their particular approaches to industrial policy, they succeeded in developing a corps of highly skilled scientists, engineers, computer scientists, and communications specialists capable of leading the world in particular facets of the semiconductor industry. That success needs to be viewed in a larger context. The regional financial crisis of the late 1990s provided an opportunity to make an assessment of longer term trends. The baseline for this cross-country and cross-time comparative analysis is drawn from a study the two authors completed in 1996 on technology generation and industrial innovation in South Korea and Taiwan.[2] At that time, we conducted a detailed set of interviews with R&D managers, corporate leaders, and government officials. We went back to many of the same people in November 1999 and conducted a series of follow-up interviews.

From afar, the crisis of the late 1990s appeared to force open relatively closed systems of governance in East Asia, to disorient corporate planners and government officials, to disrupt long-standing corporate organizational forms, and to render earlier strategies obsolete. Because of its weaker financial foundations, such effects seemed most obvious in the Korean case, where the direct intervention of the International Monetary Fund (IMF) seemed to symbolize a discrete break with the past. We were therefore expecting to find more dramatic evidence in Korea of change in financial and governance systems lying behind R & D and long-term investment planning in the semiconductor industry. Such evidence might have taken the form of decartelization in the industry, the wholesale reorganization of major corporate R&D centers, significant changes in associated government policy, diversification in general product mixes, expansion in the access of foreign investors to R&D assets in struggling or bankrupt Korean firms, and/or other indications of basic reorientation in approaches to alliances with foreign partners.

In Taiwan, our initial sense was that the country remained relatively well-insulated from financial turbulence in the region. We therefore expected to find modest changes in the character of Taiwanese patterns of innovation, both with respect to the structure of innovation processes themselves, and in relation to the pace and direction of innovation across particular industries. But we did not expect a sense of vulnerability to be altogether absent from government and industry rethinking. Heightening this expectation were the initial effects of the severe earthquake of September 1999, which hit the country's semiconductor industry hard and occurred just before our field trip.

Context

South Korea

In the early 1990s, the governments of Roh Tae Woo and Kim Young Sam faced pressures to reduce the role of the *chaebol* in the national economy and to diversify the national industrial base. In light of mixed situations in leading export markets, the ensuing drive toward de-concentration and liberalization did not always fit comfortably with the goal of enhancing national competitiveness in the here and now. Beneath tensions apparent throughout the 1990s as industries struggled to restructure themselves lay the enduring and mutual recognition on the

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[2] See Keller (1996); and Pauly (1996).

part of both government and *chaebol* leaders that the sectors capable of generating foreign exchange remained strategic for the nation. Semiconductors, especially basic memory chips (DRAMs, or dynamic random access memories), certainly represented a critically important sector in this regard. The main revenue generators were embedded within the electronics arms of the Hyundai, Samsung, and Lucky Goldstar *chaebols*, all of which were very highly leveraged.

In the late 1990s, during the presidency of Kim Dae Jung, many Korean corporations tried to reduce their historical dependence on foreign sources of credit, to reduce their bank debt while increasing their debt to non-bank financial institutions, and to increase their reliance on the bond markets. But there was no corresponding attempt to shift toward equity markets, and the major corporate groups continued to be characterized by high levels of cross-shareholding and cross-lending. The prospects for major reform and restructuring among the *chaebol* at the leading technological edge looked remote before the regional financial crisis hit in 1997.

In sectoral terms, the most dramatic new investments during the 1990s occurred in the electronics industries. From a low base, Korean firms were increasing their electronic machinery imports by 50% per year mid-way through the decade, signifying a massive expansion and re-tooling. Semiconductors and related industries had become a priority for Korean economic planners in both the public and private sectors. Firms were eligible for "policy loans" from government, in addition to their normal facilities from commercial banks. Official loans were often rediscounted at the central bank at low rates of interest (5% per annum, when market rates ranged between 12 and 15%). The government also channeled subsidies more directly and transparently to designated industries through the National Investment Fund.

Policy loans had long supported massive imports of new technology. As licensing agreements became more expensive and difficult to arrange and as the Korean economy matured, a shift toward indigenous technology development began to occur.[3] In the semiconductor industry, government research institutes were used to amass and to channel development funding for next-generation products, especially in the memory field. For example, approximately US$63 million was available in 1996 for the flagship "Next Generation Project," with half coming directly from various ministries and the other half from private industry. At the center of the enterprise until the pre-commercial phase of development was complete was the Korean Semiconductor Research Institute.

As we shall see, however, the late 1990s proved extremely challenging for Korea and its traditional approach to industrial policy.[4] A plummeting GDP, declining competitiveness in key sectors, and financial panic marked the end of the decade. Shifts in important financial and

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[3] Overall R&D expenditures rose from 0.8% of GDP in 1980 to 2.6% in the mid-1990s, a level comparable to the OECD average. The government made a commitment, however, to raising that figure to 4% of GDP by the year 2000. Government research institutes accounted for 20% of national R&D expenditures before the financial crisis, while business accounted for 70%, some of which was financed with indirect government support; universities accounted for the balance. The number of patents issued in Korea in the mid-1990s was about seven times the number issued fifteen years earlier. Over the same period, the number of US patents issued to Korean residents rose from 10 to 765. Under the terms of a ten-year program initiated in 1992, the government directly funded 30% of new technology development projects. If they succeeded commercially, firm were obliged to reimburse the government and received licensing fees in proportion to the amount of their own capital originally at risk.

[4] Relevant in this regard is Ernst (1994); and Moon (2000), pp. 65-94.

industrial structures ensued, including the bankruptcy of one of the largest *chaebol* and an historic shake-up in the management of another. The Big Three would become the Big Two (Samsung and Hyundai). We examine these and related developments below, but note here that another nearly simultaneous trend would work in the opposite direction, namely a powerful international surge in demand for semiconductors.

Taiwan

The industrial structure of Taiwan in the contemporary period has been deeply marked by an obvious and intricate network of ties between a party-dominated state apparatus and a private sector only slowly gaining real autonomy. From the 1950s through the 1970s, a paternalistic, disciplined, and Kuomintang Party-dominated government guided the development of the national economy. At the base of that economy was a large state-owned sector, which encompassed all industries deemed to be strategic. Upon that base grew a decentralized and highly flexible private sector comprised of myriad family-owned small and medium-sized firms.[5]

Beginning in the 1970s, a number of initiatives were taken to steer the Taiwanese economy away from the smoke-stack industries of the past. The government would soon establish a Science and Technology Advisory Group to oversee new policies and programs that would necessarily cross ministerial jurisdictions after the cabinet adopted a new National Science and Technology Program. Included under the aegis of the NST program were a wide variety of projects to stimulate and subsidize research and development in the promising sectors of the future. In addition, the program supported the establishment of new state laboratories and parastatal research organizations, which were explicitly mandated to support the semiconductor industry and others, including microelectronics, bio-medicine, specialty chemicals, materials science, precision engineering, nuclear energy, and aerospace. Breakthroughs achieved in national labs were transferred for commercial application either directly to chosen private firms or to semi-public joint ventures, ventures that were characterized by a high degree of entrepreneurial energy and a deliberate blurring of the lines between the official and private sectors.[6]

The Electronics Research & Service Organization (ERSO), created by the government in 1974 as an arm of the Industrial Technology Research Institute (ITRI), became the primary vehicle for stimulating development in the semiconductor industry. Its primary modus operandi was to acquire semiconductor-related technology, begin indigenous R&D, make the first moves toward commercialization, and then spin off new companies into the private sector. Official subsidies lubricated the entire process, but the gradually expanding and finally dominating role for private capital investment was its true hallmark.[7] As early as 1979, the work of ERSO engineers and technicians on the basis of technology transferred from RCA helped launch the first of Taiwan's major semiconductor manufacturers, United Microelectronics Corporation (UMC). At a time when the national capability in semiconductors was limited to packaging technology, industry was invited to invest in the new corporate entity. About 100 ERSO employees, who worked on

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[5] All things considered, however, underlying financial structures of manufacturing firms were much less highly leveraged than in the Korean case. Where average debt-equity ratios in Korea grew from 300% in the early 1970s to 500% in 1997, comparable ratios in Taiwan stayed near, and often below, 100% over the same extended period. See Leipziger (1988), p. 128; and Stone (1998), p. 18.

[6] Leipziger (1988), p. 123. See also Kraemer et al. (1996), pp. 215-249.

[7] On the strengths and weaknesses of the system, see Noble 2000.

the development of new core technologies, were effectively transferred from the lab to form the new company. ERSO took a five percent equity position, which it later sold.

The general pattern was repeated many times, and the leaders among Taiwan's semiconductor companies can all trace their roots to ERSO. Taiwan Semiconductor Manufacturing Corporation (TSMC), the current front-runner, was spun off in 1987.[8] Although the capability to conduct advanced semiconductor research now resides primarily within those now-private companies, deliberate state policy created the industry and still exerts an important influence on the course of its evolution.

The regional financial crisis of 1997-99

The financial crisis that swept through the East Asian region in the late 1990s did reshape the competitive landscape in the semiconductor industry. It transformed the context within which structures and strategies had to be adapted. But it did so differently in Taiwan and in Korea.

In Korea, the effects of the crisis were particularly severe. In Taiwan, the crisis seems to have provided more of an opportunity than a threat. In short, as the new century dawned the Taiwanese industry accelerated its evolution toward a disaggregated "foundry" model. The apparent objective was to become vital sub-contractor within overarching systems led by others. Its Korean counterpart, conversely, consolidated around the model of the integrated device manufacturer (IDM). The foundry model called for a remarkable expansion and deepening of alliancing arrangements with foreign customers, most prominently Japanese customers. The IDM model coalesced around a governmentally sanctioned domestic duopoly, which remained relatively impervious to foreign penetration. These two models, both of which rely less on direct governmental engagement in next-generation research and product development, may at the present time be taken to represent the two end-points on a global spectrum of industrial organization within the semiconductor sector.

Continuity and change in the South Korean semiconductor industry

Like a typhoon, the financial crisis sweeping East Asia after 1997 swept through the South Korean semiconductor industry with amazing swiftness. Before it passed, however, it left several significant imprints on the future of the industry. Perhaps most importantly for its long-term health, the crisis discouraged many engineers from preparing for a career within it. In interviews, we were told that reductions in workforces, and in salaries for those who remained, continue to complicate the recruitment of young engineers.

In the short run, however, a period of painful adjustment ended remarkably swiftly. In fact, some of that adjustment had begun in the early 1990s during the last downturn of the silicon cycle, which coincided with and deepened a national liquidity crisis. The new crisis nevertheless manifested itself in one major organizational shift within the industry, but after that shift old patterns of strategic behavior appear to have reasserted themselves. Talk of dramatic reform and opening within the sector, like talk of the wholesale dismantling of the *chaebols* within which

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[8] The Dutch firm, Phillips Electronics N.V., holds a significant minority stake in TSMC.

they remained embedded, proved empty. Rapidly rising revenues in 1999 simply relieved the pressure for deeper change.

The crisis was the proximate cause for the forced takeover of LG Semicon, one of the Big Three, by Hyundai Electronics. At the end of a painful and protracted process of negotiation, President Kim Dae Jung reportedly called both company CEOs to his office and explicitly demanded a merger in the national interest. The speculation among close observers is that the underlying deal takes in more than one sector. While Hyundai "won" in the semiconductors, the LG *chaebol* will eventually be granted concessions elsewhere.

The combined Hyundai-LG has significant new strengths, based on new economies of scale as well as complementary research expertise and technology assets. Once fully integrated, it will be the world's largest DRAM maker, although Samsung Electronics retains its edge as the innovator and financial leader in the sector. Still, Samsung executives certainly see the new firm as a formidable competitor once the two corporate cultures merge and short-term financial problems are addressed. Both firms will nevertheless continue to pursue broadly similar strategies as IDMs. The goal continues to be to bring as much of the electronic component and equipment value-chain as possible under one corporate roof. Controlling costs, upgrading quality, and dominating markets that are increasingly seen as commodity-like are viewed as winning strategies in the long run. Factors reinforcing the strategy, as well as indications of the continuing effects of the strategy, are reflected in recent industry data.

As Figure K-1 shows (please see all figures at end of paper), following three years of declining sales, the Korean semiconductor industry rebounded sharply in 1999. Both domestic consumption of chips and export markets snapped back during the year. After recording total sales of $7.8 billion in 1998, Korean semiconductor manufacturers achieved volumes in excess of $11.7 billion, 89 percent of which represented sales to foreign markets. At 35 percent of total exports, the US market remained the most important. Both domestic and international sales remained heavily concentrated in DRAMs.

Despite the upturn in business and the rapid turnaround from crisis conditions in the Korean economy, the psychological after-effects of the late-1990s trauma continue to course through the semiconductor industry. Many people were laid off as the industry was restructured. As a result, young engineers now cast a jaundiced eye on the prospect of a lifelong career in semiconductor manufacturing. Some are headed for Silicon Valley; others are trying their hand at start-up design houses and internet firms in Korea. Several employers and engineering professors reported to us a growing aversion among the brightest students to semiconductor research. Indeed, many student engineers now refer to semiconductors as a "3-D" industry: dirty, dangerous, and difficult. In the wake of the financial turbulence that roiled the industry, some companies and professors noted increased aggressiveness on the part of Silicon Valley firms to recruit Korean engineers, both from inside Korean companies and upon completion of university studies.

The two main survivors in the Korean semiconductor industry, Hyundai Electronics and Samsung Electronics, remain at the heart of leading *chaebol*. Internal restructuring and refocusing remains the order of the day within them, but they are excluded from broader national refinancing programs.[9] (The bankruptcy and reorganization of the Daewoo Group, which is not a major player in semiconductor-related industries, remains in a category of its own.) At the peak of the crisis of the late 1990s, corporate debt-equity ratios averaged 500 percent in Korea. In 1998, the Hyundai group nearly reached that level, but managed to cut its gearing to 341 percent of equity within the first six months of 1999. In contrast, the Samsung group was much more conservatively managed. By mid-1999, it had already conformed to new government demands to bring overall leverage ratios below 200 percent.[10]

Our interviews confirmed the common view that the semiconductor business remains central to the core strategies of the two major electronics firms of which they are a part, and of the Hyundai and Samsung *chaebols* as a whole. Nevertheless, there is some sense within the firms that the recent crisis passed too quickly to dislodge traditional operating structures and mindsets that might have benefited from some shaking up . With the recent return of revenue growth and profitability, the same strategies that contributed to industrial vulnerability in the past have reasserted themselves. Large-scale exports of end-products and extreme dependence on imported production machinery continue to characterize the Korean model in this sector. Figure K-2 indicates a significant rise in equipment imports beginning in 1998, a rise that was expected to grow as the silicon cycle surged.

The inability to produce semiconductor equipment, however, may not translate into a major vulnerability for the industry. Both Korea and Taiwan can continue to meet their equipment needs from competitive suppliers in the US and Japan.

Backward linkages in the production process continue to expand in the Korean semiconductor industry. As Figure K-3 shows, indigenous manufacturing of the raw materials going into chips continues to increase, while imports have been declining since 1995. Figure K-4, moreover, indicates that over half of the raw materials going into semiconductor production in 1998 came from Korean suppliers. That trend was expected to continue through 1999, rising from 56 percent to 78 percent.

Both Samsung and Hyundai do occasionally offer foundry services, and their willingness to do so increases during periods of slack demand for their own products. Nevertheless, their basic business strategies and organization will not permit foundry services to become predominant. With an IDM strategy aimed at controlling the entire design and production process, decision-makers in both firms continue to pursue a strategy of investing heavily in the next generation of chip manufacturing. In interviews, they were confident that they could assess risks and opportunities in-house from all crucial perspectives: capital adequacy, technical feasibility, manufacturing requirements, design specifications, product development, market demand, and so on. Most importantly, control over applied research and fundamental design issues continues to be a vital concern. As a senior vice president from one company bluntly put it, "If you have to

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[9] World Bank (1999). For further information, see http://www.worldbank.org/html/extdr/offrep/eap/speeches/pdfs.koreadoc.pdf.

[10] Data from the Korean Financial Supervisory Commission, cited in World Bank (1999). Asset revaluation was excluded.

depend on outside design for your future products, where will you go when you want to get to the next level in the technology competition?"[11]

The world-view embodied in this statement, and in the overall structure of the Korean semiconductor industry, continues to discourage the sort of disaggregated production model evident in Taiwan. Implementing plans recently announced by both Samsung and Hyundai to diversify their product lines into multimedia and non-memory will be complicated by financial management at Samsung rendered more conservative by the experience of the past few years and by the difficulties of creating an integrated workforce in Hyundai.[12] Such internal constraints make it more difficult to transport their basic model across the full spectrum of technology in this sector. Despite their stated goals, therefore, Korean semiconductor manufacturers remain largely fixated on the export of DRAMs.

The methodical search for new designs, for production efficiencies, and for new markets continues to be focused on memory chips, although there is a renewed sense at both Samsung and Hyundai that diversification into non-memory must eventually occur. In the past, such a sense of strategic vulnerability has not led to fundamental changes in operating practices or sufficient investment, by public or private sources, in the infrastructure needed to facilitate such diversification. Figure K-5 demonstrates the consequences of this failure up to 1998.

Our sense is that although senior executives within the semiconductor firms are fully aware of this dilemma, they are having difficulty breaking decisively with a traditional model that has once again begun to produce handsome returns. In December 1999, Samsung announced $2.2 billion in new investments in super-microprocessing technology (including $600 million in R&D) at the 100 and 120 nanometer level, which will accelerate plans to produce 128MB and 256 MB chips, as well as random access memory chips, by the end of 2000. By 2002, the company also expects to have invested $1.3 billion in non-memory, in order to achieve its goal of $4 billion in non-memory sales by 2005. All of this needs to be put in the context of its actual sales in 1999, which totaled about $9.3 billion: $6 billion in memory, $2.2 billion in liquid crystal displays, and $1.1 billion in non-memory.[13] But the companies seem painfully aware of their past tendency to over-invest. After the crisis, this now translates into extreme cost-consciousness and a likely shortening of planning-time-horizons, which will make a distinct break with reliance on memory even more difficult to envisage.

In the background, the lodestar guiding strategic planning in the industry remains rivalry with Japan. Despite Japan's own difficulties in recent years, the desire to emulate and catch-up remains palpable in Korean strategies in this sector. This does not close off all receptivity within Korea to more collaborative arrangements with Japanese firms, but it does reinforce limits to deeper forms of cooperation.

Related to this point, applied research is increasingly undertaken within Korean semiconductor firms themselves and not in universities. The universities have made enormous strides over the

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[11] Interview, November 10, 1999.

[12] According to an indiscreet senior executive at Samsung, "Samsung Electronics today is like an orchestra. Its members are the best in their discipline. We have the best pianist, the best violinist, the best bass player. But there is no conductor; no one to write the masterpiece." *Asiaweek,* November 12, 1999, p. 63.

[13] *Asia Pulse*, December 16, 1999.

past several years in educating greater numbers of electrical engineers and improving the quality of their education, and Samsung in particular has been an important source of funding for some university programs. But in general, companies invest in universities to gain access to their graduates, not usually to obtain research that might soon be useful in their business.[14]

The Korean government nevertheless attempted to use the financial crisis to spur university-level research of potential usefulness to industries like electronics in the long term. The stated goal is to place ten Korean universities among the top 100 research universities worldwide, a goal which the semiconductor firms support. In June 1999, the government even began to move official funding for overall electronics research from government research institutes to the universities, where research will be less tied to the directives of officials. It did so partly through newly created high-level research councils in the Office of the Prime Minister, ultimately responsible to the President.

Still, the future for the semiconductor industry in Korea is mainly being charted now within the leading firms themselves. After a brief period, decision-making power appears to be flowing away from financial managers and back to its traditional locus, the engineer-managers. The last downturn in the silicon cycle, compounded by the financial crisis, did shock industry leaders into reconsidering their traditional lack of product diversity and their reluctance to develop strategic alliances with foreign firms. Accordingly, both Samsung and Hyundai remain committed to the more aggressive development of non-memory products, eventually for end-products that involve system-on-a-chip technologies. Samsung even announced its intent to develop new products in home, mobile, and personal multimedia devices to complement current strengths in semiconductors and liquid-crystal displays.[15] Both companies continue to acquire a great deal of relevant intellectual property, but neither has achieved the highest levels of competence in design engineering, including engineering for the construction of new chip architectures.[16] The absence of a systematic national plan to emulate the kind of innovation characteristic of competitive networks of firms in places like Silicon Valley continues to hamper any serious corporate plans to reduce dependence on standardized memory chips.

The government's current flagship research program in this sector is quite modest. The "2010 Project" is aimed at building an integrated system-on-a-chip and is headquartered at the Inter-University Semiconductor Research Center at Seoul National University. The project receives approximately $25 million per year with 40 percent coming the government and 60 percent from industry.[17] The first phase, 1998 though 2003 is fully funded (with the governmental portion coming mainly from royalties on past innovations), with funding for the next five years expected to follow. In general, however, the main thrust of government's university-level policies is to

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[14] There are a few exceptions at places such as the Korean Advanced Institute of Science and Technology (KAIST), Seoul National University, and at a new resercah institute created by Samsung at Sung Kyun Kwan University. But much of this effort appears aimed more at developing computer-assisted design (CAD) training for student engineers than at advancing the state of applied research. The Integrated Circuit Design Education Center at KAIST is funding at about $3-6 million a year; while the Inter-university Semiconductor Research Center at SNU receives about $25 million per year. For further information on ISRC, see http://chips.snu.ac.kr.

[15] *Korea Herald*, December 21, 1999; *Asiaweek*, November 12, 1999.

[16] Interviews, November 9 and 10, 1999.

[17] Interviews, November 8, 1999.

facilitate the training of design engineers capable of maintaining the national strength in DRAMs, while gradually building competency in system integration. Once again, however, the main point is that the action in terms of applied research in this sector has moved out of universities and government research institutes and into the companies themselves.[18] Most basic research, such as it exists, has also moved in the same direction. Hyundai executives, for example, estimate that 5-10 percent of their overall R&D budget is invested in projects at the precompetitive stage.[19] Overall, Hyundai held R&D fairly constant during the crisis at 10 percent of sales (pre-merger), while Samsung spent 6-8 percent.

Corporate research remains focused on fairly near-term applications and incremental improvements. Inside the Korean companies, there seems to be a growing consensus that putting massive new resources into forcing the geometry of the chip may no longer be the best way to proceed.[20] As one company executive put it, "After you get to 150 nanometers, it is very difficult to see how to make the end-product economically feasible. It might make more sense to manufacture more products at 180 nm and more aggressively to seek economies elsewhere in the process of final product development and marketing."[21] Indeed, we encountered examples of Korean companies finding lucrative new markets in multimedia and optical sensing devices using "obsolete" 350 nm technology.

In short, the risk that pathbreaking new innovations will come along within the next ten years is apparently being heavily discounted in Korea. The overwhelming impression is of a rapidly maturing industry, where conventional catch-up strategies are viewed as sufficient. Once again, the upsurge in the silicon cycle makes it more difficult to turn away from this logic. Indeed, in 1999 Samsung and Hyundai saw their shares of the global DRAM market rise to 16.8 percent and 23.5 percent, respectively.[22]

In the cold light of history, however, it would seem unwise to forget the capacity of Korea and its electronics industries to surprise. A lowering of expectations has certainly occurred internally over the course of the past few crisis-years. With a degree of exaggeration, perhaps, those reduced expectations have been transmitted externally. In a sense, Korean corporate strategists have an interest in keeping those expectations low. It remains likely, however, that any future surprises will not come in terms of raw technological breakthroughs. On the basis of renewed financial returns and heightened cost-consciousness, they will likely come in attempts to build a greater degree of flexibility into production lines (by, for example, creating some auxiliary

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18 Developments inside the premier government research institutes in this sector certainly reinforce this point. Budgets have been slashed (ETRI's by 30 percent since 1998), many good scientific and engineering staff members have left, and recruiting top-notch replacements is extremely difficult. Labs are not being kept up to world standards, and there is increasing pressure for short-term research pay-offs. Interview, November 9, 1999.

19 Interview, November 8, 1999. More attention is now being paid to SRAM, flash memories, and SOC, bearing in mind the corporate goal of reducing DRAM to 65-70 percent of total production.

20 This also appears to be the rising consensus view in Taiwan, where one senior executive predicted that Moore's Law, which predicts a doubling of chip capacity every eighteen months, would be irrelevant in five years. Interview, November 15, 1999.

21 Interview, November 8, 1999.

22 *Korea Herald*, December 6, 1999. Overall, Korea's 71 information technology companies, excluding those associated with the troubled Daewoo Group, registered net profits of approximately $5.83 billion in 1999, a 1,100 percent increase over 1998. *Asia Pulse*, November 29, 1999.

foundry-like operations), in dramatic drops in production costs, and in accelerated pricing cycles for products just now coming out of the world's leading design companies. Successful efforts to exploit crises, lower expectations, refocus workforces, catch-up with leading technologies through better engineering, and leap-frog competitors are not rare in the history of the Korean electronics industry.[23]

Continuity and Change in the Taiwanese Semiconductor Industry

The Asian financial crisis did not injure the Taiwan semiconductor industry in any significant way. It did, however, provide new business opportunities and an additional impetus to move forward with a distinctive set of strategic plans. Immediately following the onset of the crisis, there was a decrease in DRAM prices as product demand shrank and the silicon cycle continued its downward dip. Taiwanese chip manufacturers nevertheless continued to export to Europe and the United States, their traditional markets. The companies remained prudently managed, and they matched low debt loads and openness to new equity infusions with highly efficient systems of production. They also aggressively sought out new technology alliances. The strategy resulted in very high levels of retained earnings once the silicon cycle turned up again. As a senior executive in one company put it, "During the crisis, the Taiwan foundry model proved itself; the Korean IDM model showed its deficiencies."[24]

With average debt-equity ratios across its corporate sector below 100 percent, more than five times less than the Korean figure, prudent financial management provides an obvious clue as to how Taiwan insulated itself from financial contagion in the years following 1997.[25] Financial controllers within the leading semiconductor manufacturers held to standards even more conservative than the national norm.[26] The main integrated-circuit firms in Taiwan therefore came through a difficult period in 1997 and 1998 with few scratches. As Figure T-1 demonstrates, across the separate sub-sectors of design, fabrication, packaging, and testing, industry revenues have grown markedly throughout the 1990s, with only a slight setback in 1998. (Again, please find all figures at end of paper.)

In terms of gross revenues, chip fabrication remains the leading sector within the industry and has consistently accounted for over half of industry revenues since the mid-1990s. In 1999, fabrication accounted for 56 percent of industry revenues. And sales grew explosively during the year, an increase of nearly 58 percent over 1998. Accounting for most of this expansion was the foundry side of the business, which rapidly asserted its dominance. Taiwan foundries, IC manufacturers producing chips mainly for others under contract (including, most prominently,

[23] On this theme, see Kim (1997).

[24] Interview, November 15, 1999.

[25] IMF data cited in Stone (1998).

[26] TSMC's internal debt/equity target is 40 percent, at most. Its target for return on equity, in turn, is a minimum of 20 percent. During good times, it may exceed 35 percent. R&D expenditures are said to be well in excess of 10 percent of gross revenues per year, and may approach 50 percent of net income. Interviews, November 18, 1999.

TSMC and UMC, were forecast to generate revenues of $4.2 billion in 1999. This forecast represents a 66 percent share of the global foundry business.

Generally speaking, the success of the Taiwanese chip fabrication business as whole rests on earlier strategic decisions by both government and industry. As Figure T-2 demonstrates, those decisions translated into capital expenditures to create capacity that were massive in both absolute and relative terms.

In short order, this investment brought an industry once seen as capable only of high-volume standard chip production to the brink of world leadership. In 1997, the best estimates publicly available were that Taiwanese fabs would be mass producing at the 180 nanometer level within three years. In fact, that era dawned in 1999. Current the Taiwan Semiconductor Industry Association (TSIA) estimates see 150 nm as feasible by 2001 and 130 nm by 2003. Industry labs are now working at the 130 nm level and expect to be at the 100 nm level by 2003.[27]

At the heart of Taiwan's current chip fabrication strategy organized around the foundry model lies the conviction that the semiconductor manufacturing business is now mature. As in Korea, the now-conventional guess is that the big innovative leaps have already taken place. If this is correct, the future belongs to the low-cost producer. It could be wrong, but again as in Korea enormous financial bets are now being placed. The bets are being placed on scale, process technologies, and production efficiency. Differently from the Korean case, however, associated financial risks are being spread broadly.

In the short to medium term, the process-level innovators of the Taiwanese foundry see themselves creating a new high-tech service business. In the long run, the foundry model may well turn out to have been a means to another end. For now, however, it reflects the contemporary phase of a long-term and highly successful national strategy. During the depth of the oil crisis in the 1970s, a plan emerged to diversify the island's economy and quite consciously not to follow neighboring countries in the creation of heavy industries. Electronics soon emerged as a centerpiece, and the semiconductor foundries now represent one of the signal successes of the original plan.

The model depends on achieving capacity utilization rates near 100 percent in dedicated chip foundries. It also depends on each foundry maintaining an ability to expand capacity quickly, even during an economic downturn. The objective is always to be in a position to meet anticipated future demand from the chip designers who, in effect, "own" part of the foundry's production line. When such demand is delayed, some foundries have found it necessary to turn to back to their own basic DRAM production. This deepens the silicon cycle by depressing prices, and makes it more difficult for competing IDMs to weather the storm. At such times, chips made in foundries with excess capacity are often sold cheaply to local electronic appliance assemblers in Taiwan and then exported in such finished products as computer motherboards. In this way, antidumping rules applied in foreign markets can be easier to circumvent.

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[27] ERSO/ITRI database, April 1999. UMC data indicate a current ramping up to the 130nm level from 180nm. In 2000, they are scheduled to begin some production at 120nm The explicit goal is 90nm by 2003. The principal medium will be copper, not aluminum. Interview, November 15, 1999.

Very high capacity utilization rates in the Taiwanese foundries result from a high degree of flexibility. Unlike fabrication facilities run by IDMs, foundries are programmed to change quickly from one type of chip to another. As a result, Taiwanese firms—including chip makers separate from but owned by the big foundries—are in a position to search out and fill market niches much more nimbly than their Japanese or Korean rivals. The key, as one foundry executive explained, is to be able "to turn from logic chip production to DRAM production overnight. Over here, we do 50 to 100 technologies at the same time and we do it routinely. Who else can do that?"[28] This kind of flexibility, and the design libraries constructed over the years, enables the foundries to harness scale economies and cut costs.

A principal source of advantage for the foundry rests on its ability to convince customers that their intellectual property, their basic designs, will be treated as proprietary. The customer must trust the foundry completely. The foundry must assure its customer that it will not become the vehicle for sharing IP with rivals, even rivals using the same foundry to produce similar products. When such a level of trust is established, a single-minded focus by the foundries on aggressively improving production efficiencies and cutting costs can lock in and deepen customer relationships. In the long run, the foundries are betting that low prices will convince even customers capable of producing chips themselves that they do not need to maintain their own internal sources of supply. Strategists within the Taiwanese industry believe, furthermore, that customers using the foundries as supplementary sources during boom times will eventually see the wisdom of relying on the foundries as primary sources. The fact that customers are increasingly also partial equity holders in the foundries reinforces that expectation.

In this regard, the last hurdle for customers capable of competing with the foundries relates to their needs during particularly critical periods in a product cycle. With their own production facilities, for example, IDMs can respond quickly to surges in demand that they themselves may confront. If they use foundries for more than just production buffers, they accept a risk that such responses may be slowed in the future. The question then becomes, what is such flexibility and control worth? If the foundry can come close to that value in pure pricing terms, the foundry is betting that many customers will see the wisdom of giving up that flexibility and reducing their own level of control. The outcome would necessarily entail a deepening level of structural interdependence. Again, trust built on an enduring competitive advantage in both cost and quality terms underpins the foundry model and the vision of the future it encapsulates.

At ground level in the leading foundries, a complicated but tremendously lucrative compensation scheme appears to be crucial to building and motivating the workforce capable of delivering the kind of flexibility the model requires. Salary and bonus schemes are reportedly so generous at TSMC and UMC, for example, that they can count on attracting the most talented people in the industry. Compensation levels soared during the 1990s, and it now became routine for Taiwanese engineers in the United States to repatriate.

Alliances also deserve a central place in any consideration of how the foundries actually operate. Formal linkages with customers clearly strengthen the foundries in very practical ways and help them to keep their production costs ultra-competitive. They can become especially important when recessions hit major end-use markets. Driving alliance formation as well is an evident preference among the foundries to build new production sites, both in Taiwan and

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[28] Interview, November 16, 1999.

internationally, through the use of shared equity arrangements and guaranteed purchase contracts. The scale and scope of such alliances have expanded substantially in recent years. Figure T-3 shows the alliance structure of the Taiwanese semiconductor industry as of April 1999.[29]

A particularly noteworthy set of alliances have emerged between Taiwanese foundries and Japanese IDMs. Firm relationships, for example, already exist between TSMC and Fujitsu, Winbond and Toshiba, Mosel and Oki, and Macronix and NKK, Sanyo and Matsushita. Last summer, TSMC also announced a new tie-up with Mitsubishi Electric (through its Powerchip venture in Taiwan) and UMC acquired 56 percent of the shares of Nippon Steel's microchip subsidiary.[30] Such alliances sometimes provide supplementary equity resources to help build the next generation of fabs, but more importantly they usually help take out much of the financial risk associated with their construction by providing guaranteed chip-purchase contracts. Asked to reflect on the possibility that such arrangements may prove purely short-term and that Japanese partners would always be very careful to retain control over the core technology, one Taiwanese executive simply asserted, "If the Japanese cannot beat you, they will share with you before they give up."[31]

Current alliance strategies also suggest the future expansion of Taiwanese foundries abroad. There will not be a hollowing out of their Taiwan bases, but there will be increasing attempts to reassure customers of the ultimate security of their supplies by building some new fabs near their customers in key overseas markets. Likely locations include the northwest United States, Ontario, Japan, Western Europe, and Southeast Asia. A production site typically includes three or four complementary fabrication facilities. There are several factors driving this move, including political uncertainty regarding Taiwan's future, recent earthquakes, and the associated need to reassure customers of the security of their supplies. In North America, incentives from local governments reinforce larger strategic rationales. Proximity to major population centers and good universities with renowned engineering departments, as well as access to relatively inexpensive labor markets (especially in Canada but also in certain regions of the United States), are all seen as mutually reinforcing.

To what extent can the Taiwan foundry model actually be replicated abroad? Interviews suggest that engineers will be paid prevailing wage rates in new locations. Will the new employees, who are therefore effectively paid less than their Taiwanese counterparts perform at the required level? Are there other sources of workforce motivation and flexibility that will not transfer easily abroad? These and other key questions now confront strategic planners in the large semiconductor companies themselves. They see no alternative, however, to at least some selective geographic diversification.[32]

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[29] Two recent changes involve the merger of TSMC and Acer and TSMC's buyout of Worldwide Semiconductor. *Business Wire*, December 31, 1999; *Nihon Keizai Shimbun*, January 7, 2000. In addition, UMC and Hitachi have announced a new joint venture in Japan.

[30] *Agence France Presse*, June 28, 1999.

[31] Interview, November 15, 1999.

[32] On the question of potential large-scale expansion into mainland China, there is a diversity of views. The most common view at the moment is that the cultural, financial, and technical environment is not yet in place to replicate the experience in Taiwan. The situation is clearly, however, a fluid one.

Whatever the ultimate vulnerabilities of the foundry model, it appears to be succeeding today. In 2000, Taiwan is expected to become the world's third largest semiconductor producer, after the United States and Japan. Total capital investments during the year should approach $2.5 billion.[33] With the conversion of its Vanguard subsidiary to foundry operations, TSMC alone will soon have a production capacity of 3.9 million wafers, which will put it in the number two position globally, just behind Intel which now produces 4 million wafers a year.[34] As Figure T-4 indictaes, the global foundry market is expected to exceed $8 billion in this year. The Taiwan foundries are expected to claim some two thirds of that market.

Whether rapid growth can be sustained in the long run is very much tied to the quality of the research base being put in place in Taiwan today, a base now mainly located within the leading firms themselves. Very little applied research in this sector is currently taking place in Taiwanese universities. There is, however, a clear understanding of the role of universities in pushing the national innovation system ahead. In the pioneering days of the semiconductor industry—that is, 10 to 15 year ago—the applied impetus came not from universities but from government research labs, especially from the Industrial Technology Research Institute. Today, new resources are being pumped into other sectors within ITRI and within the universities. Hsinchu Science-Based Industrial Park, where the leading fabs are located, has been built around the National Tsing Hua University and the National Chiao Tung University. As in Korea, the Taiwanese semiconductor firms mainly now value the universities more because of their anticipated future personnel requirements.

Engineers continue to repatriate to Taiwan in large numbers, mainly from the United States, and often after acquiring several years of experience in top US semiconductor companies. As Figure T-5 shows, in the five years ending in 1999 approximately 1,963 foreign-trained Taiwanese semiconductor technologists returned to take jobs in Hsinchu Park. Over the five-year period 1993-1998, the number of Ph.D.s at Hsinchu Park increased by more than a factor of four from 244 to 985, while the number of Masters-level employees increased from 2,314 to 10,033 over the same years.[35]

The flow of Ph.D.-level scientists and engineers in semiconductor-related fields repatriating from the United States to Taiwan, however, is expected to slow appreciably over the next several years, as indigenous training programs increasingly satisfy demand.[36] At the top end of the industry, the US university system is still seen as both unique and accessible. As one company executive put it, "MIT is a global resource. No one else has it." But training in the United States is no longer considered crucial across the board. "Electrical engineers trained in Taiwan," are

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[33] *Nihon Keizai Shimbun*, January 21, 2000.

[34] *Nihon Keizai Shimbun*, January 13, 2000.

[35] For further information on Hsinchu Science-Based Park, see http://www.sipa.gov.tw/seconde/hsip/hsi11000_08.htm.

[36] The number of Taiwanese nationals receiving semiconductor-related Ph.D.s from US universities fell steeply from a record high of 296 in 1995 to 173 in 1998, an eight year low. Moreover, the vast majority of these new Ph.D.s—127 in 1998—indicated they planned to stay in the United States, with only 37 planning to leave the country. It may be that these young Taiwanese scientists and engineers will follow the pattern of their elders, i.e., repatriating after several years of on-the-job training, but if they do, they are likely to do so in fewer numbers. National Science Foundation (2000), special tabulation by R. Lehming, January 29.

just as capable as most trained in the United States. In any case, they are good enough."[37] The Chinese phrase for "good enough" can also be translated as "just right," which is widely taken to imply the need now to emphasize profitability in the here-and-now and not at the expensive frontiers of semiconductor research where returns are less certain.

The consensus view in Taiwan at present is that the foundry is the model of the future because the kind of value that used to be added in the early stages of research and product design is now increasingly being added at later stages in a production process capable of greater disaggregation. In this context, leading corporate strategists assume that the cost of the fabs of the future, barring an unexpected technological shift, are unlikely to be affordable by one firm. A certain portion of the future production of a fab then becomes a kind of franchise, and customers will increasingly become partial owners of shared production facilities. As one outspoken company vice president explained, "The Taiwan foundry producing even the latest semiconductors simply provides a high-tech service. On the basis of available raw materials and efficient production skills, they now operate like McDonalds does."[38]

Taiwan's foundries now account for 12 to 15 percent of the global production of integrated circuits, a number expected to grow to 20 percent over the next two years. This growth may be hard to manage efficiently; it will surely produce negative outcomes for some companies and positive outcomes for others. Fabless companies will increasingly be able to enter directly into competition with current market leaders, using advanced production technologies and design libraries provided by the foundries. In so doing, they will gamble that the foundries can manage their growth to meet market demand as cyclical upswings become more extreme. Many industry watchers are optimistic that the foundries will expand rapidly while maintaining service and quality levels, while others are more skeptical and expect problems with execution of complicated strategies. As the foundries increase their share of global production and their access to advanced semiconductor designs, the possibility that they may enter into deeper forms of strategic alliance with some of their customers in order to compete more effectively with others cannot be dismissed. The critical issue revolves around who will actually create, own, and control the intellectual property at the heart of the semiconductor production processes of the future.

Taiwan's semiconductor companies believe that they can either develop the future technology they need internally, license it, or otherwise gain it through alliances, increasingly with Japanese firms. But Taiwan as a whole may succeed in expanding its own Silicon Valley-type innovation environment much more quickly than most observers now imagine. An ambitious new national strategy is clearly evolving, a strategy which envisages a decentralized but synergistic industrial infrastructure within a more open Taiwan. According to an April 1999 study, over 200 integrated-circuit companies are now in operation and software development capabilities are expanding rapidly. Companies are proliferating in the areas of design, mask, fabrication, packaging, testing substrate, leadframe, wafer, and chemicals.[39] An upgraded research base is

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[37] Interview, November 16, 1999.

[38] Interview, November 15, 1999.

[39] ERSO/ITRI, April 1999.

being fostered jointly by government and industry in information technology parks, such as Hsinchu Science-Based Industrial Park, Tainan Science-Based Industrial Park, and their satellites.

Most recently, both private investors and the national government have aggressively targeted the software industry, undertaking the development of the Nankang Software Park in Taipei, where over 5,000 people are expected to be engaged in software production in the year 2000.[40] This "government assisted, privately funded" park provides a facilities mainly for small firms engaged in software development, industry-specific application development firms involved in IC design, factory automation, computerized home appliances, and telecommunications.[41] Web-based firms are also starting up. Revenues generated in the Park are forecast to reach $300 million by the end of 2000.[42]

Such purposeful efforts may eventually succeed in combining sufficient venture capital with a critical mass of expertise on many additional aspects of chip design, architecture, software, and fabrication. In the long run, this deepening of indigenous design capability could pose profound challenges for the contemporary version of the foundry model. Keeping customer designs proprietary is difficult at the best of times. The customer must be assured that innovations are not leaked to competitors whose chips may even be produced on the same line in the same foundry. Even more importantly, they must have complete confidence that the foundries themselves will not copy their designs. All of this was relatively easy to accomplish when there existed a relatively low design capability in the Taiwanese semiconductor industry as a whole. But as one senior executive of a Taiwanese DRAM producer, himself recently returned to Taiwan after a long career in Silicon Valley, forecast: "Today most intellectual property in the Taiwan industry is coming from the Valley. In five years, it will come from here."[43] Taiwan currently can only boast world-class expertise in the production of standard cell microchips. The belief that the expertise now being developed will simply remain at that level is becoming implausible.

The big Taiwan foundries are already capable of producing central processing units (not yet highest-end); they are now building associated first-class design libraries and library tools. More complicated application-specific ICs are coming into those libraries now. The foundries are already gearing up, moreover, for the coming system-on-a-chip era by producing to world standard most of the separate component parts required and by creating the production capability necessary to "put all of the pieces together" quickly. Internal R&D horizons are now being pushed out to ten years by the leading firms. It is true that the production of semiconductor equipment machinery is not in sight within Taiwan itself, but the capital required to continue acquiring leading-edge machinery is available. Indeed, Taiwan is expected to be the world's

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[40] For further information on the Nankang Software Park, see http://softwarepark.centurydev.com.tw

[41] Liu (undated). Dr. Liu is chairman of the Century Development Corporation, which is building the Park. In his terms: "The establishment of the Park is a manifestation of the government's determination to accelerate the development of [Taiwan's] software industry. Software companies in the Park will be able to take advantage of a variety of tax and financial incentives offered by the government."

[42] Data provided by Park officials, January 2000.

[43] Interview, November 15, 1999.

largest investor in semiconductor equipment by the year 2002.[44] Finally, now moving squarely into the center of new strategic thinking within the industry is competition from, and opportunities within, mainland China.

The present version of the foundry model is unlikely to be the last. In less than fifteen years, Taiwan created a new industry. The motivation is clearly there to keep the model behind that success a dynamic one. For executives within the Taiwanese semiconductor industry as well as for national planners, the necessity at the current historical juncture is to tread very carefully between maintaining the confidence of key customers and alliance partners and continuing to move up the technology ladder.

Conclusion

Strategic change and structural continuity mark the contemporary history of the semiconductor industry in both South Korea and Taiwan. The regional financial crisis that began in 1997 was not severe enough to disturb their overarching trajectories of development. In both cases, the industry originally represented an important step up the latter of industrialization. They were, and remain, national champions. But the locus of strategic adjustment, like the locus of crucial research and development for the future of the industries, is now deeply embedded not in government agencies but within the leading semiconductor manufacturers themselves.

The financial crisis did have relatively more consequential effects in South Korea, where it precipitated political intervention and a new round of consolidation. It did not, however, force fundamental change in competitive strategies designed around a vision of low cost-high quality production in commodity-like markets. The essential gamble behind such a strategy, which continue to focus on DRAMs but aims to capture an entire product value chain within an integrated device manufacturing model, is that underlying technologies are stabilizing. Even if revolutionary innovations arise, the bet is that successful commercialization will lie far enough in the future to permit the Korean industry to absorb new technologies and adjust its production-centered corporate structures. In such a context, the core of current strategies is to strengthen traditional production and scale advantages from a national base now dominated by two firms. This does not preclude moves to improve tactical flexibility. For example, attracted by the success of foundries in booming international semiconductor markets, a few Korean producers in mid-2000 began to shift some of their operations into a foundry mode.[45] But a decisive break with longstanding managerial convictions about the deepest strengths of the Korean industry remained difficult to envisage.

In Taiwan, a government-led phase of industrial development has now decisively given way to a company-led phase. Like their Korean counterparts, moreover, the leading companies have embarked on a strategy emphasizing low-cost production. Unlike the Korean case, however, the overarching industrial model is increasingly disaggregated. At the moment, the core element within the Taiwanese semiconductor industry is the foundry, which uses leading-edge production technologies to manufacture chips for others. Conservative financial management by foundry owners left them relatively unscathed by the regional crisis of 1997. The crisis nevertheless did

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[44] *China Economic News Service*, September 14, 2000.

[45] See *Far Eastern Economic Review*, October 12, 2000.

present opportunities, which were enhanced by the nearly simultaneous upswing in the silicon cycle. A gradual separation from government involvement, deepening quality on production lines mainly through advanced research and application within companies themselves, planning for the building of new fabs outside of Taiwan, and a remarkable expansion in strategic alliances with European and especially Japanese firms—all marked a new phase in the development of the industry in the late 1990s.

The flexibility required to take advantage of new opportunities and adjust to a changing environment is not new. It has been evident within the Taiwanese semiconductor industry since its inception. The corporate structures and applied technological advantages built around the foundry model will continue to adapt to changes in global markets, but the particularly interesting adjustments to watch will involve Japan on one side and mainland China on the other.

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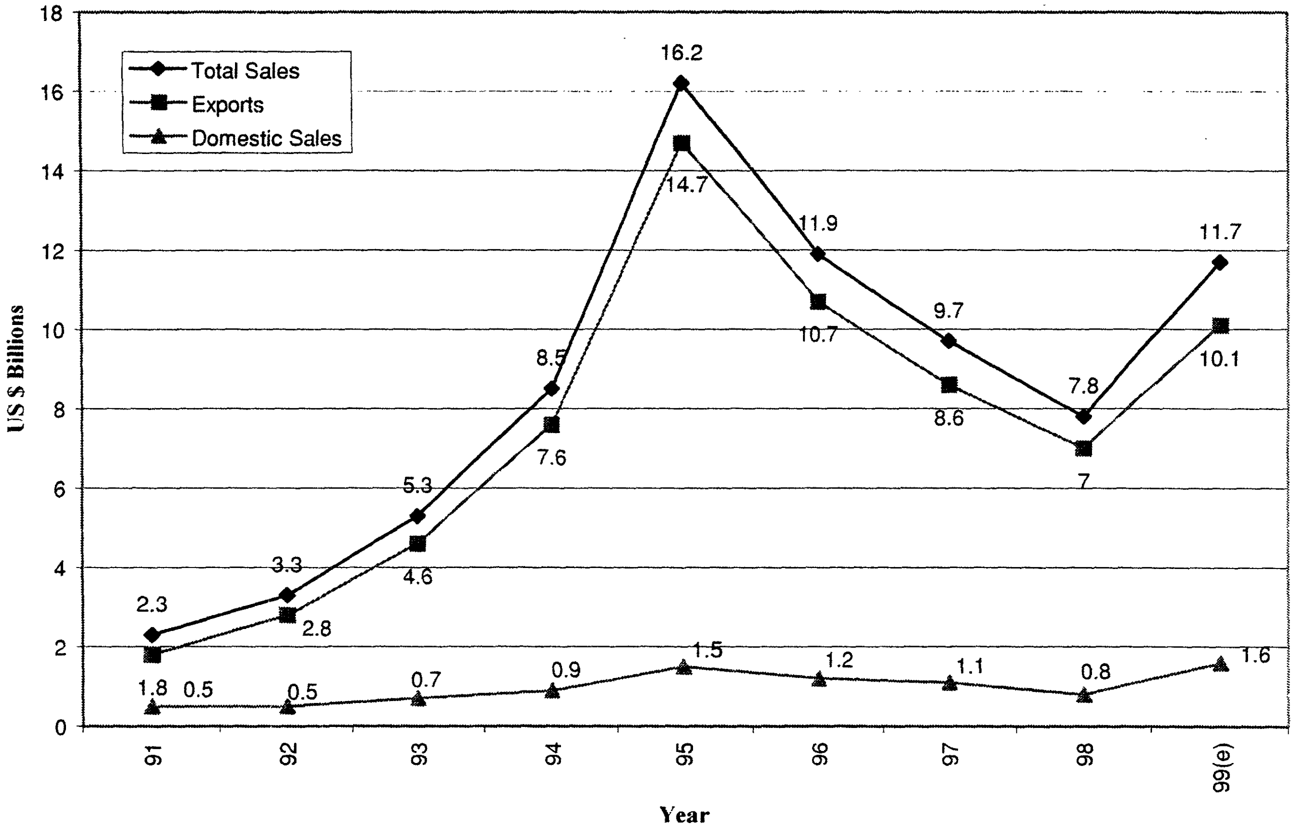
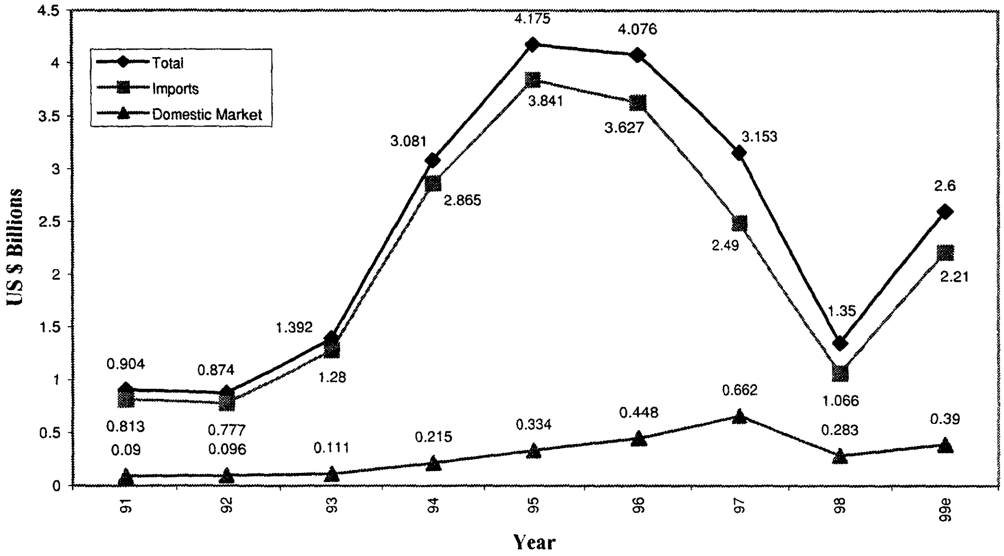
Figure K-1: Korean Semiconductor--
Domestic Sales and Exports, 1991-99(e)



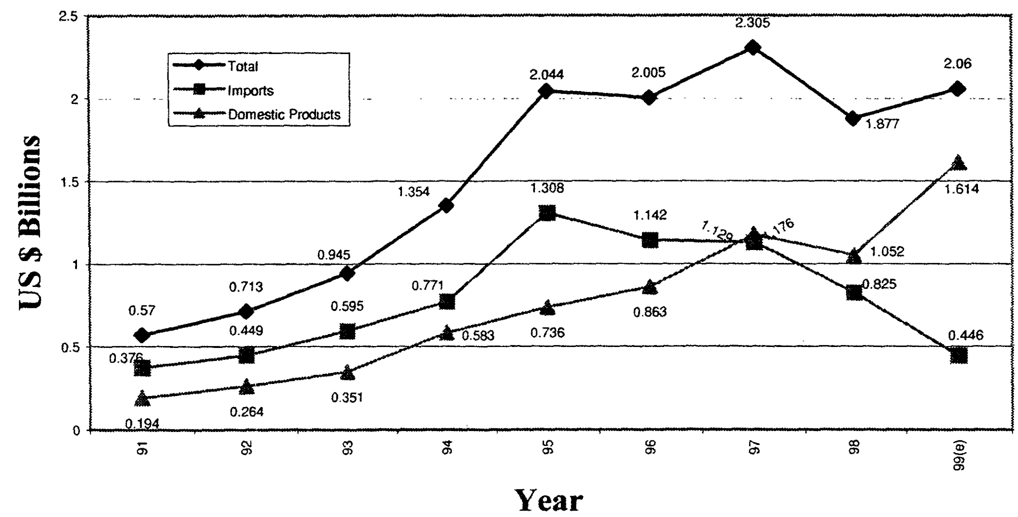
Source: Database compiled by Korean Semiconductor Industry Association, January 2000.

Figure K-2: Korean Semiconductor Equipment Market, Imports and Domestic Production, 1991-1999(e)



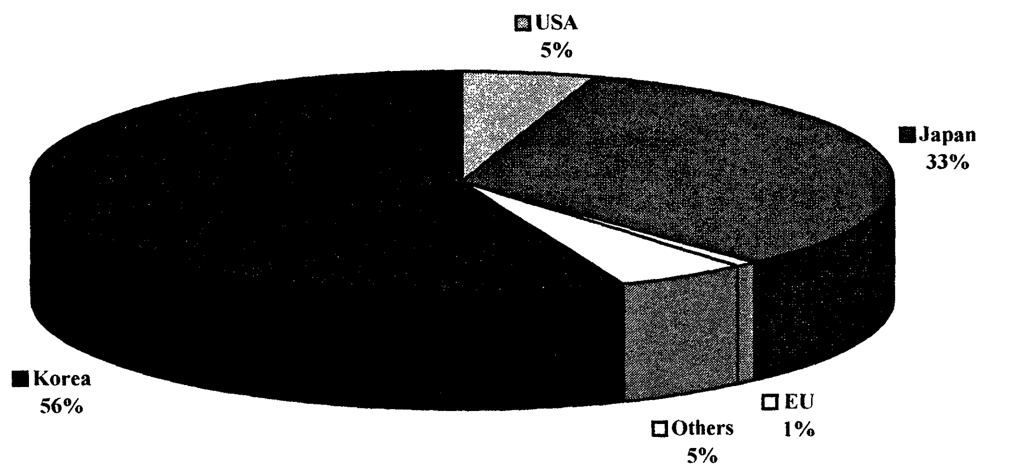
Source: KSIA, September 1999.

Figure K-3: Korea Semiconductor Material Markets--
Domestic Production and Imports, 1991-1999(e)



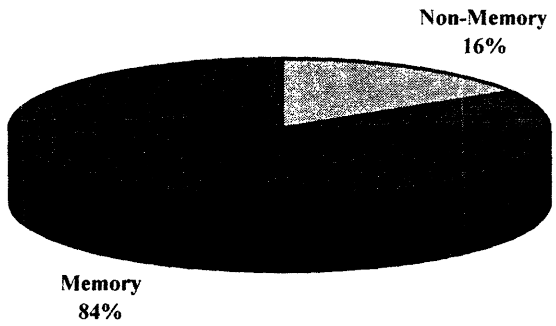
Source: KSIA, September 1999.

Figure K-4: Korean Semiconductor Materials by Source, 1998



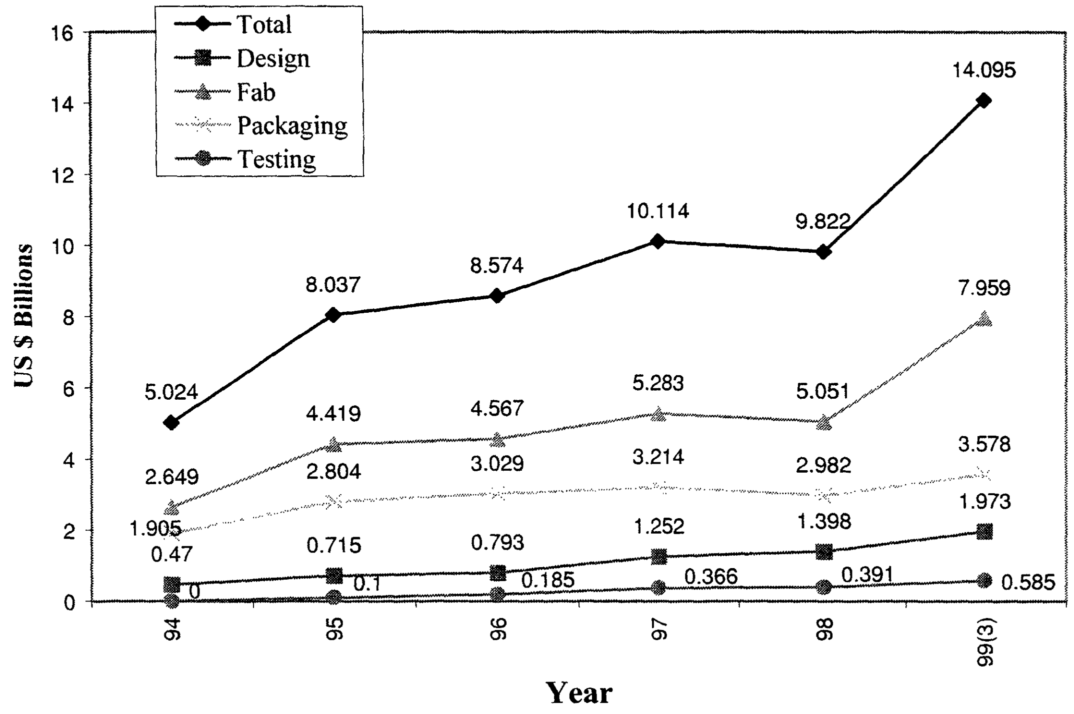
Source: KSIA, Sept. 1999.

Figure K-5: Korean Semiconductor Sales by Product, 1991-99(e)



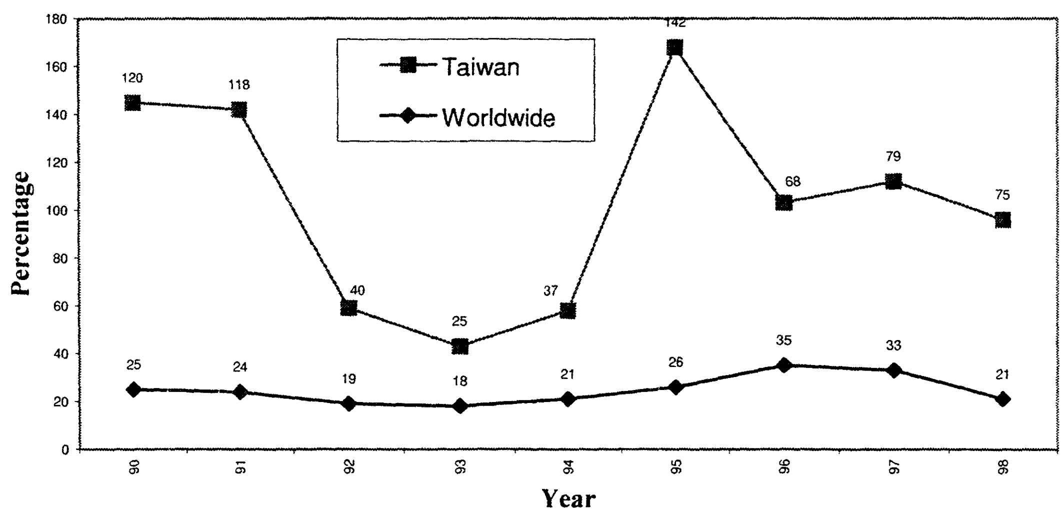
Source: KSIA, January 2000.

Figure T-1: Revenue of Taiwan Semiconductor Industry



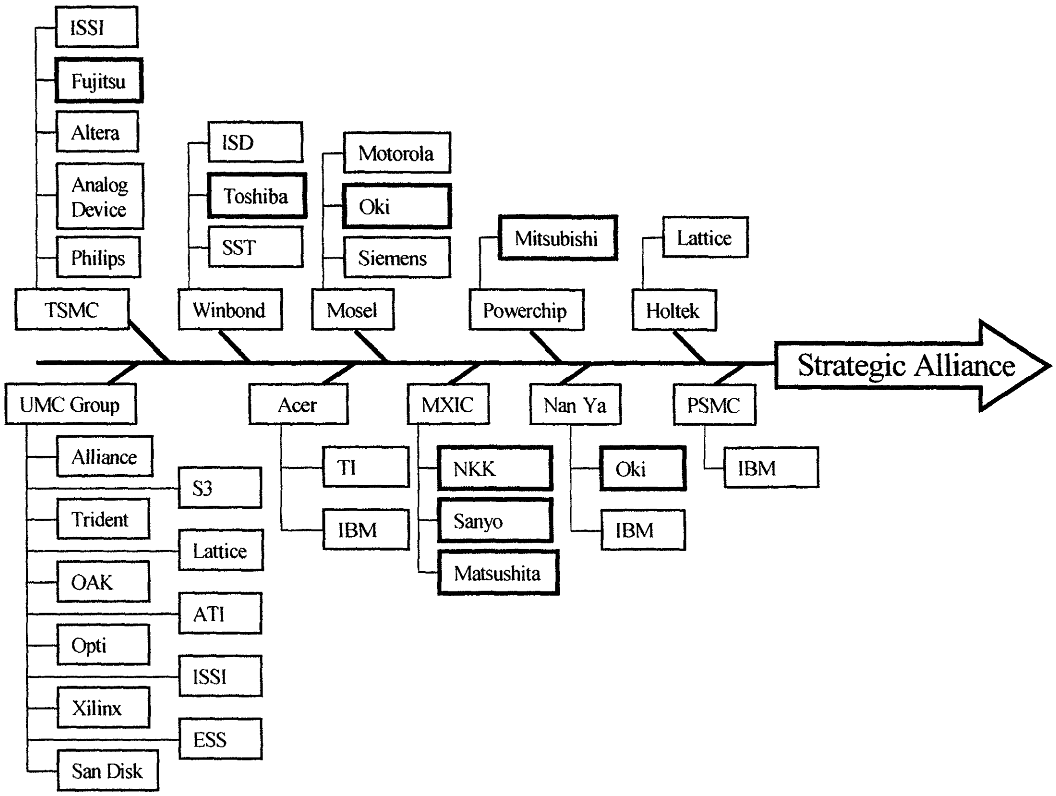
Source: Databases compiled by Electronics Research & Service Organization (ERSO) and Industrial Technology Research Institute (ITRI), October 1999.

Figure T-2: Ratio of Capital Expenditure to Revenue--
Taiwan and Worldwide, 1990-98



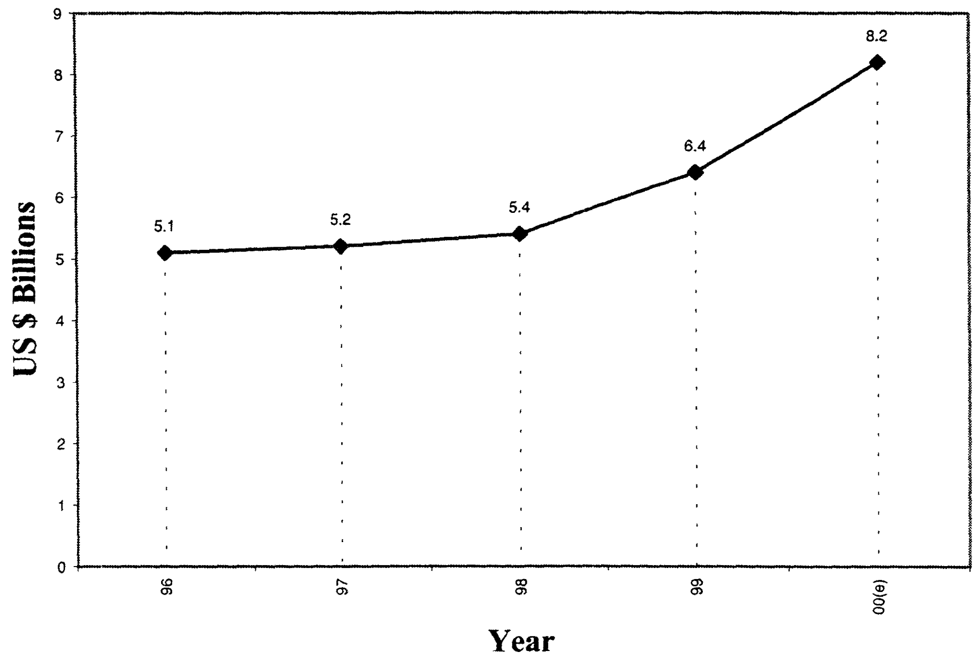
Source: ERSO/ITRI, April 1999.

Figure T-3: Taiwanese Semiconductor Industry Alliance



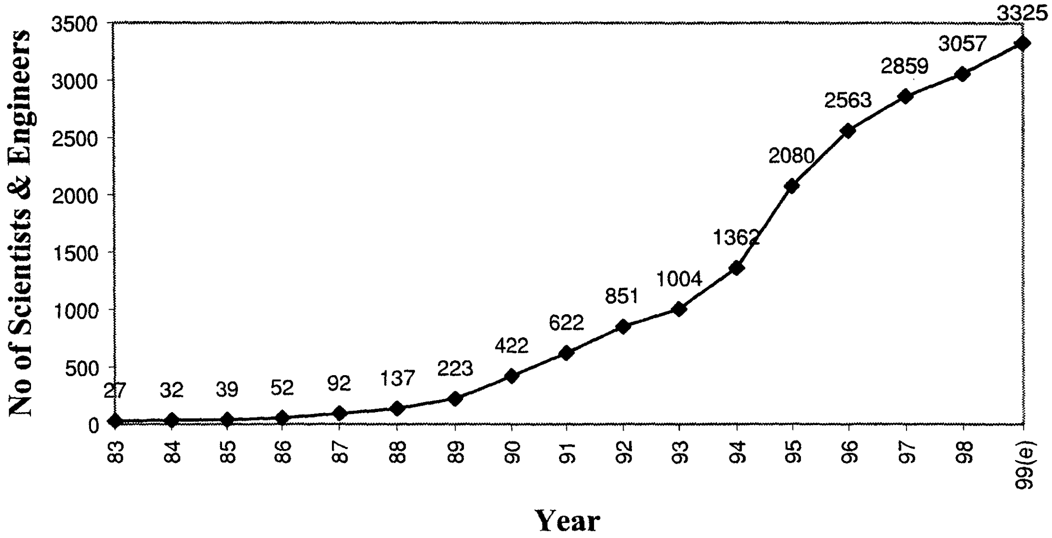
Source: ERSO/ITRI, April, 1999.

Figure T-4: Worldwide Foundry Market 1996-00(e)



Source: Dataquest, ERSO/ITRI, April 1998.

Figure: T-5: US-Trained Scientists and Engineers Returning to Hsinchu Science Park in Taiwan, 1983-99(e)



Source: Database compiled by Administration, Hsinchu Science Based Industrial Park, November 1999.