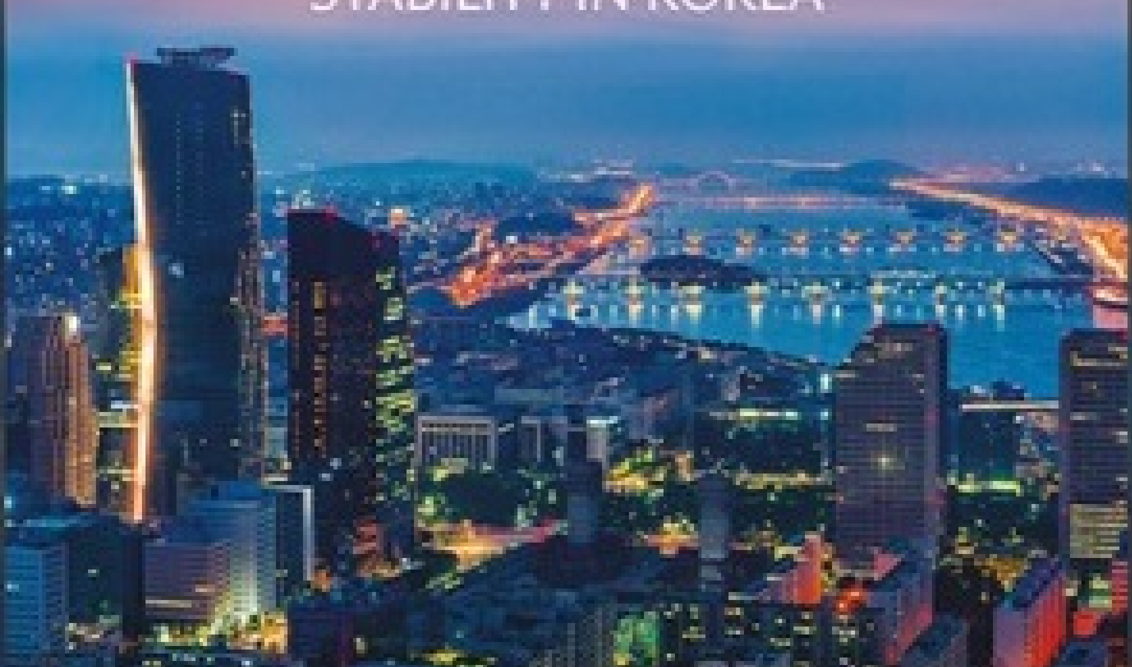
Elgar

Keun Lee

Economic Catch-up and Technological Leapfrogging

THE PATH TO DEVELOPMENT AND MACROECONOMIC STABILITY IN KOREA



8.4 THE WINNING AND LOSING STORIES OF CATCHING-UP

8.4.1 The Automobile Industry

According to Pavitt's (1984) classification, the automobile industry is a scale-intensive industry and less science-based than electronics. Compared to electronics, the innovation path is more predictable and there is less frequent concept change. Frequency of innovation is also low. The knowledge base of the automobile industry has such features as that tacit knowledge is more important than in other industries. This is related to the fact that each automobile component is less separable from the main body of a car of a specific type and thus it is difficult for a global market to be formed for each component. In contrast, PC parts and peripheries are sold in different markets as independent commodities. This is related to the high degree of standardization of PC parts, which means producers have to compete with rival producers worldwide. Such a difference between the automobile and the PC implies that to the extent that producers are able to internalize the important technology or know-how, they can prolong their competitiveness and latecomers are likely to enjoy more room for raising their own competitiveness and related viability.

The above-mentioned technological regimes of the automobile industry gave some advantage to catching-up firms like Hyundai Motors in Korea that could mobilize enormous R&D resources on the specific target. The enormous amount of R&D expenditure devoted to engine development was critical, and this was supported and pushed through by the top management headed by Mr. Chung Ju-Young. Such commitment was also possible because the R&D target was clear and the risk was not that great. Hyundai's engine development was a typical case of catching-up led by huge investment.

Another interesting aspect of the project, however, is that it involved something that can be called an "unlearning" (Nonaka 1988; K. Kim 1994). According to Nonaka, unlearning means organizational restructuring to cut out the existing routines and rigidities in order to create new capabilities and synergy. To launch the engine development project, Hyundai established a new in-house R&D center in Mabuk-li which inherited almost nothing from the old R&D center in Ul-san. It was thought that the Ul-san center had become "spoiled" by just assimilating and adapting, in a rather passive manner, imported technology (including engines), and thus was not suitable for the new job of developing the engine itself.

Hyundai's development of its own engines, fuel injection system, and other parts were basically fruits of its own initiatives, without help from the government, which basically provided only domestic market protection. Mitsubishi in Japan did give some help, but for the most part the major car assemblers in the world were reluctant to transfer technology to Hyundai. Hyundai, therefore, had to get access to the external knowledge of specialized R&D firms, like Ricardo Co. in England. Since their business was not to produce and sell the cars but to sell the technology itself, their attitude toward latecomers, like Hyundai, was different from that of car assemblers. This could be termed something like "open protectionism" such that although rising techno-nationalism is a fact, international technology markets are not yet tightly closed and there exist diverse business entities who are ready to transfer technology to latecomers if certain conditions are met.

Hyundai's technological development also involved a process which can be classified as a stage-skipping catching-up in our framework. When Hyundai started to develop engines, the carburetor-based engine was the standard type. But, knowing that the trend of engine technology was moving toward a new electronic injection-based engine, Hyundai decided to develop this latter type of engine, rather than following the old track in developing the standard engine (K. Kim 1994). By succeeding in this project, Hyundai was able to reduce the gap in engine technology in a very short period of time. Now the technological capability of the Korean firms represented by Hyundai can be said to have reached the stage of product design in terms of the states of reverse engineering. For up to medium-sized passenger cars, the localization ratio was higher than 90%, although core parts for luxury cars are still imported.

8.4.2 D-RAM Industry

According to our model, the technological regime of the D-RAM industry is characterized by a high frequency of innovation and a more predictable path of technological trajectory. While less uncertainty in technological trajectory means a smaller handicap for the latecomers, a high frequency of innovation means more things to catch-up. Now let us look into the details of this industry to see how it can provide some chances for conglomerate-style firms like Samsung, especially late entry and market success chances based upon cost advantages.

In the D-RAM industry, technological innovation within the same generation chip is oriented toward process innovation to reduce unit costs, and thus scale matters in this respect. Between the memory chips belonging to different generations, for instance 16 M bit chips to 64 M bit chips, product innovation is oriented toward upgrading.[10] In this memory chip industry, the degree of upgrading (capacity difference between generations) is very big, and thus different generation chips cannot coexist for long; old generation chips are soon replaced by new generation chips. Furthermore, transferability of technological knowledge between different generations is not so strong as to pose serious handicaps to late entries (Lee and Lim 2001). These features mean that conglomerate-style latecomer firms who build a production facility on a large enough scale for the new generation chips can enter and claim some share in the market without much interference from the incumbent firms. Actually, if one looks at the evolution of D-RAM chips in the world, one notices that the leaders in this market have evolved from the specialized firms belonging to the large conglomerate firms such as Samsung (C. Kim 1997).

The above feature of the D-RAM industry gave important advantages to the Korean firms as latecomers. A firm's innovation effort (R&D expenditure) is a function of not only its own technological capability but also of expected additional profits from the next generation chip business. Incumbent leading firms are less strongly inclined to initiate next-generation chip development since they want to fully exploit profits from the current generation chip. In contrast, additional profits from the next-generation chip business are bigger for the current followers than for the current leaders, relatively speaking.[11] Owing to their size, as conglomerates with strong financial resources at hand, Korean firms, especially Samsung, have found it easy to enter this market.[12] Korean firms are very experienced in process-innovation-driven competition and also strong in scale-intensive R&D and production. Thus, we take the D-RAM chip industry as an example to show that the advantages of the latecomers are strong owing to the special nature of the technology, and the Korean firms exploited this advantage. In a sense, this case can be also called a case of technological followership, borrowing the word from Bolton (1993) and L. Kim (1997a). In other words, Korean firms, especially Samsung, watched the growth of the D-RAM industry led by forerunners like Intel, and entered the market only after the market size of the industry was sufficient for the large conglomerate firms to be able to enjoy some of the advantages.[13] Late entry by the conglomerate firms after watching development was possible since they had the financial capability.

Looking back on the path of the development of the memory chip industry in Korea, we classify this as a case of stage-skipping catching-up, where Korean firms mostly followed the same path as the forerunners but skipped several stages. In the 1970s, several Korean firms started wafer processing and absorbed low-level technology, and the firms took the form of the direct foreign investment firms or private OEM firms with the facility provided by the foreigners. There was no systemic government help except some minor assistance from a GRI called the KIET (Korea Institute for Electronics Technology; now known as ETRI). The period from the late 1970s to the early 1980s is one of absorption of high-level technology and many foreign companies sold their shares to Korean firms, and Korean chaebols like Samsung took over these firms. Through its own initiatives, without government help, Samsung first started to produce 64 K bit D-RAM chips in the early 1980s. At that time, the government's position was said to be such that Korean firms had to start from 1 K bit D-RAM, but it was the decision of the private firms to skip the 1 to 16 K bit D-RAM to enter directly into 64 K bit D-RAM.

How was that possible? Access to the external knowledge base partially holds the key to this question. The time that Korean firms including Samsung were considering production of 16 K bit D-RAM was the transition period in the world D-RAM industry from 16 K to 64 K. Samsung was able to buy 64 K bit D-RAM design technology from Microelectronic Technology, a small US-based venture company, and manufacturing technology from the Japan-based Sharp. In the case of Hyundai, it bought design technology from Vitelic but tried, without success, to develop its own manufacturing technology (C. Kim 1994). Later, Hyundai had to borrow manufacturing technology from the Texas Instruments company. Thus, such stage-skipping catching-up was made possible by access to the external knowledge base in the form of licensing.

A couple of years after starting to produce D-RAM using borrowed manufacturing technology, Korean firms began to develop their own circuit design technology, first developing and producing 256 K bit memory chips in the mid-1980s. Samsung chose to develop its own design technology for 256 or higher K bit D-RAM as it was not easy or cheap to buy the design (L. Kim 1997b). In this process, the role of overseas R&D outposts in Silicon Valley and returning brains was critical. It is observed that Samsung's 256 K bit D-RAM chip developed by its Silicon Valley team turned out to be better than the Japanese counterparts (L. Kim 1997b). After Samsung's independent development of 256 K bit D-RAM, some foreign companies were willing to sell Samsung their 1 M bit D-RAM design technology, but Samsung refused to purchase the technology since it though it could develop it on its own (L. Kim 1997a).

Government industrial policy lagged behind the progress made by the private initiatives (Lee and Lim 2001). Only in 1986 did the government initiate the formation of a semiconductor R&D consortium with the participation of Samsung, LG, and Hyundai to develop successive generation memory chips starting with 4 M bit chips and going finally to 256 M bit chips. The development of 256 M bit chips by the Korean firms was a world first event, and in this sense the Korean firms have now become "path-leaders" and the technological capability of the Korean firms has now reached the final stage of the creation of a new product concept and its design in the reverse engineering.

In sum, the case of D-RAM can be considered as a stage-skipping catching-up that relied upon access to the external knowledge base in the form of licensing and overseas R&D outposts and took advantage of the mass production and investment capability of conglomerate firms. It should also be noted that the special characteristics of D-RAM provided the latecomers with some advantages associated with the fact that the innovation path and hence catching-up target is well-defined. However, continuous development of the new generation chips involved some explicit knowledge, and the Korean firms overcame this gap with help from the government, overseas R&D posts, and returning brains from the US.

8.4.3 Telecommunication Industry: CDMA Cellular Phone

The development of the CDMA cellular phone system and initiation of services in Korea is one of the most successful cases of a path-creating catching-up or leapfrogging, led by a private–public collaboration. When the Korean firms and the government authorities considered development of the cellular phone system, the analogue system was (and still is) dominant in the US, and the TDMA-based GSM (Global System for Mobile Communications) was the dominant system in Europe. However, the Korean authorities (Ministry of Information and Telecommunication) paid attention to the emerging CDMA technology, with higher efficiency in frequency utilization and higher quality and security in voice transmission.

Thus, despite great uncertainty over the development of the world's first CDMA system, as well as the strong reservations expressed by the telephone service provider and the system manufacturers, such as Korea Telecom, Samsung, and LG, the Ministry and the ETRI decided to go along with CDMA. One of the main reasons for the decision was reported to be the consideration that if Korea just followed the already established TDMA (GSM), the gap between Korea and its forerunners would never be reduced and thus catching-up would take even longer. Thus, Korea chose a shorter but riskier path, and had success. Although it was in 1995 that the first test of the CDMA system was conducted, the Korean government first designated the CDMA system development as a national R&D project as early as 1989. This implies that the Korean authorities were quite well informed in the trend of telecommunication technology and had foresight. In 1991, the contract to introduce the core technology from, and to develop the system together with, the US-based Qualcomm was forged. In 1993, the Ministry declared CDMA to be the national standard in telecommunication. Now, Korean subscribers (more than 6 million) account for more than 75% of the worldwide CDMA subscribers, and Korea also started the CDMA-based PCS service in 1997.

According to our model, the high frequency of innovation and high fluidity of trajectory of the telecommunication industry does not give the latecomers any incentives for R&D effort. Expected profits and other related gains from first-mover advantages served as a strong attraction, and the high risks were shared by the government-led R&D consortium and knowledge alliance with Qualcomm. The ETRI also contributed to reducing technological uncertainty by providing accurate and up-to-date information on technology trends and by identifying the correct R&D targets that were more promising than alternatives.

In achieving the leapfrogging by taking a different path, the role of the government was critical in taking the initiative to form a R&D consortium with private firms and pushing the firms ahead. However, it should be noted that the core technology was bought from Qualcomm, and thus Korean producers still have to pay heavy royalty fees, equivalent of 5.25% of sales revenue per mobile phone unit, in addition to a lump sum for the technology licensing. The localization ratio in the mobile phone was only 30%, and most of the core part, including the MSM (Mobile Station Modem) electronic chip, was imported. However, in 1997 ETRI succeeded in developing the MSM chip by itself,[14] and subsequently Samsung declared in 1999 that it could now produce most of the core chips required in CDMA mobile phones. That means the completion of the core part assimilation stage in the reverse engineering. The Korean firms are now worldwide leaders in CDMA-based phones, and they are now entering the final stage of creation and design of new product concept in the reverse engineering.

8.4.4 PCs

The PC industry in Korea started with simple assembly in the late 1970s. Small venture companies, like Sambo and Quenix, manufactured for the first time in Korea an 8 bit PC by reverse engineering. At that time, no foreign companies were interested in investing in the Korean market through JVs. They were more interested in export sales in Korean markets. Thus, Korean producers had to stand on their own feet. However, with the shift to the 16 bit PC after 1984, they felt the need to import higher technology by licensing since they realized it was very difficult to produce the 16 bit PC by reverse engineering only. Thus, most Korean PC firms switched to OEM producers targeting exports. The government also designated the PC as a target for promotion and provided domestic market protection; imports were restricted in 1984 and export requirements were imposed on foreign JVs. However, other than these measures, there was no direct government involvement in R&D or collaborative R&D between the public and private sectors.

The 1985 to 1989 period was the best time for the PC firms in Korea, which emerged as the hottest site for worldwide OEM production of PCs, exploiting economies of scale in the large conglomerates (chaebols). This change was triggered by the voluntary opening of PC architecture by IBM, which allowed worldwide licensing of IBM PC BIOS. Numerous manufacturers of IBM-compatible PCs thrived all over the world. Riding this new wave most successfully were the Korean producers who had accumulated some know-how in large-scale assembly in electronics and price-based competition with some learning-by-doing effects. However, even during this growth period, most Korean firms were OEM producers conducting semi knocked down (SKD)-based assembly, and thus were able to acquire only low-level technology. With technological capability increasing, they switched from simple OEM to private OEM, and at the same time, Korean firms realized the limits of the OEM production as a window for technology absorption. It acted rather as a hindrance since the foreign partner firms designated the specific manufacturers' parts to be used in assembling the PC (Lee and Lim 2001) and therefore locally made parts were hardly ever adopted. Furthermore, foreign partners were reluctant to contract further licensing of more advanced technologies.

Thus, Korean producers felt the need to conduct their own R&D, and at the same time, the role of government also changed from providing simple market protection to R&D support and demand creation by government procurement. The public and private R&D collaboration began and the Korea Computer Research Association was set up in 1985. The government lifted the restrictions on PC imports in 1987 and, subsequently, in July 1988, the import restrictions on PC-related peripheries were also abolished. In the late 1980s and the 1990s, Korean producers succeeded in the local production of the PC mother board, memory chips, and other peripheral parts, such as hard disk drives (HDDs), dot printer heads, laser printer engines, LCD, and CD-ROM drives. Nevertheless, they still had to import items such as most logic chips, HDD heads, printer controllers, and laserbeam scanning units (LSUs) for laser printer engines.

Since the early 1990s, Korean PC industries had faced a sudden depression; exports plummeted, and now there are few PC exports from Korea, with an exception of Sambo Co. selling E-machines. Korean producers are now switching to PC peripherals such as monitors, hard drives, and CD-ROM drives. Several factors can be identified as the cause for the sudden downfall. First, we note change in the nature of the industry through the development of technology. The importance of a large-scale assembly process declined with the rise of chip-sets which integrated the different functions of several chips into one chip. Thus, Korea lost its comparative advantage as an assembly site. Second, we note firms' strategic mistakes. Korean producers did not respond well to the rapid shortening of life cycles in PCs. For example, the PC industries around the world switched very promptly from the 286 PC, to the 386 PC, to the 486 and 586 PC; however, Korean firms, because of the huge investment made by

Korean chaebols in the 286 PC assembly lines, continued too long with the 286 PC and were left behind. Third, the rising royalty was also a burden for assembly-oriented PC firms in Korea.[15]

Beyond the above-mentioned direct causes for the weakening of the PC industry, there were more important structural problems associated with the technological regime of the industry. First of all, it should be noted that the PC industry is, according to Pavitt's (1984) classification, a science-based industry. The PC industry is characterized by very high frequency of innovation, and, furthermore, concept change is frequent, and thus it is very difficult to predict the direction of future product development. This feature makes the catching-up more difficult as the latecomers rise up the ladder. For example, Korean producers say that if they concentrate, they should be able to develop microprocessors. However, they are concerned that sudden changes in the CPU (central processing unit) generations or technological trajectory will render the development by latecomers of the CPU useless or out of date. For example, it was reported that Intel and Texas Instruments developed a totally new series of microprocessor which will substitute the 286–386–486–586 series. This means that even if the latecomers succeed in producing the old-style chips, they might soon become obsolete.

The initial success in the 1980s by the public–private R&D collaboration in developing a PC was possible because they identified a target product which met the market trend. However, after then, the continuous changes in products and market conditions made such an arrangement ineffective. In other words, given the high unpredictability, the late-comers cannot target future development items with any certainty. Actually, this is a problem that requires help from other components of the national innovation system, such as universities and GRIs. The network between firms and academia is perceived as weak and universities' R&D resources are perceived as having not been effectively utilized in Korea. Firms' in-house R&D alone cannot tackle the problem adequately.

Another factor that must be mentioned is the peculiar nature of the PC parts markets. Quite differently from, for instance, automobile parts, PC parts are fairly standardized over the world since the PC is now produced by module-based production, and thus there exist markets for every part. This means that parts producers should compete globally. This also makes it difficult for the followers to catch up with the leaders. Given the high uncertainty of success with parts development and the unreliability of locally made parts, final assemblers in Korea felt no need to develop core PC parts or to use locally made parts. They were preoccupied with the price competitiveness of the final goods.

This was the background that caused Korean PC producers to turn increasingly to domestic markets. Their technological capabilities were somewhere between the core part assimilation and product design stages in terms of reverse engineering, and they were falling short of leading the industry by developing new products on world markets. In this light, the situation was similar to the case of consumer electronics, such as audio components. Both industries were relying on Korean-specific tastes or markets. However, such a strategy cannot be sustained for long. For example, as Microsoft had further improved its English–Korean software, Hancom, the largest software producer in Korea, was losing its market share.

8.4.5 Consumer Electronics: Audio and Video Equipment[16]

As is well known, consumer electronics has been the leading export sector of Korea. Korea was for some time the world's second largest exporter, second only to Japan. However, after 1988, the peak year, export growth slowed, and now China has replaced Korea as the world's second largest exporter. Such change was related to the erosion of competitiveness of Korean products in world markets, Korea being somewhat sandwiched between the advanced countries and the next-tier NIEs. Thus, from the 1990s, Korean producers put more emphasis on the domestic markets, modifying their products to capture Korean-specific tastes and demand.

To dig into the cause of the rise and fall of the Korean consumer electronics industry, we must begin with a brief overview of technological development in this industry. In the 1970s, the main channels of the technology transfer were direct foreign investment, and Koreans were able to learn from their JV partners. As foreign investors gradually lost their interests in their Korean businesses owing to export-oriented government policies and the continuing restrictions of domestic markets, the Koreans took over the businesses and began independent production from the late 1970s (Y. Kim 1997). Thus, the channels of technology transfer changed from informal learning from partners to formal absorption by licensing. During the 1980s, Korean producers, mostly chaebol firms, imported low-level technologies which enabled them to locally produce marginal parts. At this stage, the role of the government was critical in encouraging localization of parts production as well as restricting foreign penetration by taking restrictive FDI and import policies.

The pattern of technological development and innovation in the Korean consumer electronics industry can be said to have progressed from the stage of "duplicative imitation" (L. Kim 1997a) of the standardized product at its mature stage in the product life cycle to "creative imitation"

(L. Kim 1997a) of the new products since the mid-1980s. During the duplicative imitation stage, Korean chaebols used the imported production facility to carry out mass production of standardized products. Any innovation was mainly process-oriented innovation based on learning-by-doing, and there was a reliance on economy of scale to maintain price competitiveness. The second step in the duplicative imitation was localization of generic-use parts requiring low-level technology, and there was also some learning-by-doing in parts production. After duplicative imitation came the stage of creative imitation of new products. Now, the Korean producers shifted their effort to imitating and locally producing, with lower costs, new products, not mature products, developed by advanced economies like Japan. Localization of the marginal parts and, more recently, some core parts also started initially with imitation. Here, some effort to add "Koreaness" to the Japanese-developed products was also made so that it may be called creative imitation. However, even at this stage of creative imitation, Korean producers are weak in new product innovation, namely in creating new product concepts and designing them, and they are still relying on imported core parts for high-end goods.

The difficulty facing consumer electronics can be explained by our model as follows. First of all, the Korean firms were having difficulty in securing continuing access to the external knowledge base while their own R&D capability had not grown sufficiently to make them stand-alone. As they were getting closer to the forerunners and demanding more advanced technology, the forerunners in the advanced countries became more reluctant to allow technology transfer in the form of licensing. On the other hand, their lack of product innovation capability can be seen from the composition of the R&D expenditure by the Korean firms. In average consumer electronics firms, the expenditure for "basic research" accounted for only 8.2% and "development for mass production" was 65.9% of total R&D expenditure (Y. Kim 1997: 427).

Why was it so difficult to acquire innovation capability or why were the Korean firms not putting enough money into R&D in this field? The answer had to do with the technological regime of the industry. Here we have to take note of the changing nature of the consumer electronics industry. Consumer electronics had increasingly become science-based rather than supplier-dominated as in the past. The trend was that the product life cycles were getting shorter and shorter, which meant higher frequency of innovation and increasing technological uncertainty. Lacking the capability to lead the product innovation, the Korean firms were just busy in adapting and imitating successive new products developed by the forerunning firms. Since they cannot be sure of the chance for market success of their own product-to-be, they cannot put in a strong R&D

effort either; they can enjoy neither stable cost margin nor reliable quality differentiation.

From the 1990s, as technology licensing was getting more difficult, Korean firms, like Taiwanese firms, had started to increasingly resort to overseas R&D outposts, international M&A, and strategic alliance. At the same time, as we said before, their interests had turned more to domestic markets, and their "product innovations" had mostly been adaptive ones to capture Korean tastes. For example, LG developed a refrigerator which was especially suited to storing Korean foods. Of course, this meant a smaller market size, and this strategy can last only as long as foreign rivals do not develop and sell Korean-specific products or are forbidden to enter the market itself.

8.4.6 Machine Tool Industry

In Pavitt's (1984) classification, the machine tool industry is a typical specialized supplier industry, where tacit knowledge accumulated from the interface between producer and customer firms is very important. The technological regimes of the machine tool industry used to be characterized by a relatively low frequency of innovation and low fluidity of technological trajectory, although the increasing introduction of computer technology into this industry has been changing the regime from low to medium or high frequency and fluidity. Despite such technological features of machine tools, the incentives for R&D effort by the latecomer firms were low. This has to do with the fact that the expected chance for market success of developed products has been perceived as rather low because they cannot safely expect any such benefits as cost edge, quality differentiation, or first-move advantages. The case of machine tools is different from automobiles and other consumer durable goods in the sense that latecomer producers were not able to achieve catching-up with forerunning firms either by simply importing production equipment and buying licensing of product design and production engineering or by conducting their own R&D (Lim 1997).

To understand this industry, we have to start with observations on the special properties of the knowledge base of the machine tool industry. In the machine tool industry, the important knowledge about production is tacit and cannot simply be embodied in production equipment. The equipment used in the production process is usually general-purpose machines. Therefore, the skills accumulated by the workforce are more important. Furthermore, technical licensing cannot solve the problem of poor design capability in the product development stage since technical licensing tends to be confined to a specific set of models of machines. The producers who have to produce diverse products to meet diverse user needs are required to have the capability to modify machine design, which, however, cannot be acquired easily by studying abroad or through technical licensing.[17] This is part of the reason why catching-up has not been easy in the machine tool industry despite its relatively slow speed of innovation.

It is also important to note that investment in R&D alone cannot solve the problem of poor technological capability in the machine tool industry. R&D capability originates mainly from knowledge accumulated during product development. In terms of accumulation of tacit knowledge, a serious difficulty lies in the fact that Korean firms are reluctant to use domestic machine tools due to their poor quality and low precision level. In this matter, even government policies to encourage the use of domestic products were not and cannot be effective. Since the quality of the machine tools employed directly determines the quality of the output, customer firms, sensitive to the quality of their own products, cannot afford to use the domestically produced machine tools. Then, the weak domestic market, not to mention the poor export markets, provide no opportunity to accumulate tacit knowledge by expanding production and interacting with more customer firms. Thus, the latecomer can expect neither cost advantages nor quality advantages. This aspect is one of the most fundamental differences between the machine tool industry as a capital goods industry and other final goods industries, such as automobiles or consumer electronics. To the extent that numerically controlled (NC) device production is scale-intensive, the limited size of the market implies serious barriers to the development of the NC device industry, let alone the factor of the weak interface with the customer firms and weak development of SMEs (Lim 1997).

In general, the difficulties of latecomer firms, such as Korean firms, have to do with the both tacit and explicit aspects of the technology. However, with the shift to specific-purpose machine tools from the generic-purpose machine tools and, furthermore, with the rise of NC machine tools, the importance of explicit core technology is increasing. In particular, the emergence of CNC (computerized numerical control) machine tools has given more importance to electronic know-how than to the skills embodied in the engineers (Lee and Lim 2001). As the machine tool industry absorbed the technology from mechatronics, product innovation occurred more often, resulting in life cycles being shortened. In terms of core technology, such as the NC device which accounted for the largest share in the total value of the NC machine tools, only 30% of the domestic NC machine tool products used the locally made NC devices (Lee and Lim 2001). This is due to the low level of precision of the domestic products; for example, for the generic-purpose NC lathe and the high-precision lathe, it was only

50%, and 1%, respectively, of the level of the products from advanced countries like Japan or Germany (Lee and Lim 2001). The Korean firms in this industry can be said to have reached the stage of developing some peripheral and core parts in terms of technological development.

8.4.7 The Model and the Three Patterns of Catching-Up in the Six Industries: Summary

In the above, we have explained the three different patterns of technological catching-up, namely stage-skipping, path-creating, and path-following using the cases of six industries. Here let us try to present a summary of how the model is used to explain the different evolutions of the six industries.

We will begin with the two cases of stage-skipping catching-up in the automobile and D-RAM industries. The Korean firms skipped the stage of the carburetor engine to jump into a fuel-injection engine in automobiles, and skipped 1 to 16 K bit D-RAM to jump directly to 64 K bit D-RAM. In both industries, the innovation path and hence catching-up target were more clearly defined, and the latecomers just skipped some stage in the path.

First, in terms of the model, the automobile industry is characterized by low frequency of innovation and more predictable technological trajectory, thus incentives for R&D effort were greater than otherwise and the Korean firms were able to rely on cost advantage for market success. However, even in this case, access to the external knowledge base (e.g., Ricardo Co.) was critical. According to the stages of development of technological capabilities, the Korean companies, especially Hyundai, can be said to have reached the stage of being capable of designing their own products. However, the Korean car makers still rely on cost edge, rather than quality differentiation or first-mover advantages in market competition.

Second, we classify D-RAM as an industry with high cumulativeness (high frequency of innovation) and more predictable trajectory. Thus, we must say that incentives for R&D effort are mixed for latecomer firms, but for the Korean firms with conglomerate structures, the expected chance for market success based on cost edge was perceived to be great, and the Korean firms were able to purchase production facilities and product designs during the initial stage. Thus, given a predictable technological trajectory, the Korean firms, in collaboration with the GRIs, poured in an enormous amount of R&D input and overcame difficulties posed by high cumulativeness. Sufficient financial resources for R&D were critical since the frequent product innovation, namely chip generation change, for example from 1M to 4M, tended to make each successive round of required investment bigger and bigger, and occurred at increasing speed. Also critical was the access to the external knowledge base in the form of reverse brain drain and overseas R&D posts. By the 2000s, the Korean D-RAM industry had reached the final stage of technological development, namely creation of new product concepts and designs.

CDMA is an example of a path-creating catching-up or leapfrogging. Given the high frequency of innovation and high fluidity of trajectory, the telecommunication industry did not give the latecomers any incentives for R&D effort. However, this difficulty was ameoliated once the Korean R&D consortium gained access to the external knowledge base by a co-development contract with a US-based venture company, Qualcomm. Furthermore, by taking a different path from the forerunners, the Korean firms were able to expect market success based on first-mover advantages and the high risks were shared by the government-led R&D consortium. The consortium also contributed to reducing technological uncertainty by providing accurate and up-to-date information on technology trends and by identifying the appropriate target for R&D projects and collaboration. In this light, our finding is somewhat different from the observation in Perez and Soete (1988), as we find that the Korean entry and leapfrogging were not driven by the endogenous generation of knowledge and skills but by collaboration with foreign companies. Anyway, the Korean firms had reached by the 2000s the stage of creating and designing new products in terms of the stages in reverse engineering.

Now let us turn to the cases of consumer electronics (audio components) and PCs, which we perceive as having taken the path-following strategy in catching-up. Up to a certain stage the strategy was successful and resulted in increasing market shares, especially in PCs and consumer electronics when the Korean firms were able to buy mature technology with licensing from the leading companies and enjoyed price competitiveness associated with cheap labor and production engineering capability. However, as the licensing started to become difficult or more expensive and the second-tier NIEs emerged, the Korean firms suddenly faced a setback in market shares. At the same time, their technological capabilities had not grown sufficiently to allow them to stand-alone. The Korean firms in these industries are characterized by weak product design ability and low localization of core part production.

According to our model, the difficulty over technological development in the PC and consumer electronics industries has a lot to do with the technological regimes of these industries characterized by the high frequency of innovation and high fluidity of technological trajectory. In these industries, important production as well as design technology tended to be embodied in core IT components and software. Therefore, simply purchasing production equipment was not enough to enable the latecomers to catch up with the forerunners. Furthermore, the Korean firms were not able to expect market success because they could not enjoy the benefit from either cost edge or product differentiation for a long period of time. In sum, both the R&D capabilities and the incentives for R&D effort were low for these industries. Given the frequent product innovation and fluid trajectory, the R&D target was difficult to fix for public and private joint effort. Thus, in these industries, even government help is not enough to overcome the fundamental difficulties imposed by the technological regimes of these industries. Any reliable chance for market success based on either quality differentiation or first-mover advantages is not guaranteed, and therefore the government has limited its role to providing protection for domestic producers. In these two industries, technological capabilities of the Korean firms in the 1990s were still somewhere between the stages capable of developing core parts and designing their own but imitative products.

Finally, there is the somewhat unique case of the machine tool industry. The machine tool industry used to have a relatively low frequency of innovation and fluidity of technological trajectory. Despite such technological features of machine tools, the expected chance for market success with product development by the latecomer firms appears low; they cannot safely expect any such benefits as cost edge, quality differentiation, or first-move advantages. In the case of machine tools, the government also found it difficult to impose protection for domestic producers. The reason was related to the fact that in this industry, the customer is not an ordinary consumer but the domestic firms that are producing exportables for world markets. The Korean firms were reluctant to use domestic machine tools due to their low quality and low level of precision. The Korean firms in this industry can be said to have reached the stage of developing some peripheral and core parts in terms of technological development.

These complex stories of the six industries are summarized in Table 8.4, although we are concerned with possibility of this being misleading owing to its very simplified nature.

8.5 SEVERAL POLICY-RELATED ISSUES

8.5.1 Technological Regimes vs. Institutions: Policy Issue 1

To the extent that tacit knowledge is important in R&D and to the extent that it is acquired by experience in production engineering and product development, the existence or creation of markets is important. Without markets, the accumulation of knowledge from the experience of production

Table 8.4 Stories of the winners and losers in market and technological catching-up

	D-RAM	Automobile	Mobile Phone (CDMA)	Consumer Electronics	PC	Machine Tools
A. Catching-Up Patterns and Level of Technological Capabilities						
Market shares	rapidly increased	increasing slowly	increasing	decreased after peak	decreased after peak	very slowly increasing
Catch-up pattern	stage-skipping	stage-skipping	path-creating	path-following	path-following	path-following
Technological capability	product concept & design	most core parts & product design	product concept & design	some core parts/ design	some core parts/ design	some core parts/ peripheral parts
B. Explaining Factors						
Frequency of product innovation	high	low	high	high	high	low
Fluidity of technological trajectory	low	low	high	med./high	med./high	low
Competitiveness of developed products/its source	high/cost edge & first mover	high/cost edge	high/first mover	low	low	low
Access to knowledge base	R&D outposts & reverse brain drain	Foreign R&D firm & license	Foreign venture co. & license	used to be license from the leading co.	used to be license from the leading co.	used to be license from the leading co.
Role of government	joint R&D	market protection	joint R&D	market protection	market protection	incentives for domestic products

is impossible. Then comes the first role of the government which gives the latecomers the guaranteed markets through domestic market protection and export subsidies. Another role of the government might include joint R&D with the private sector to conduct product innovation when the R&D target requires more explicit knowledge that could not be acquired simply by accumulating production experience. Specifically, the desirable scope of government activism and the effectiveness of it can depend on the technological regimes of specific industries, among other factors. In other words, we consider the technological regime as "fundamental," based on which other policy or institutional variables act. In addition, we allow another "fundamental," that is, market competition. In other words, firms have to win the markets based on cost edge, quality differentiation, or first-mover advantages. The government cannot easily manipulate these two fundamentals without incurring substantial costs. Given this, what can the government do?

As discussed above, the Korean government conducted joint R&D with the private sector in D-RAM and CDMA mobile phones, whereas they provided market protection only for automobiles, consumer electronics, and the PC industry, and offered incentives for the use of domestic products in the case of the machine tools industry. These stories help us delineate the role of the government.

First, we would like to state that when there is greater technological uncertainty, namely more fluidity, the role of government in catching-up should be limited to providing market protection of fixed duration. We think that in the cases of PC and consumer electronics (audio components), direct government involvement in R&D would not be effective or at least too costly in overcoming fundamental technological uncertainties. The story of the short-lived public–private R&D consortium in PCs can be an example in revealing the limits of such a program in terms of its duration and scope. The case of CDMA appears to violate this principle. The CDMA case, of course, is somewhat exceptional. The risky and exceptional nature of this case can be seen from the still uncertain future of competition between CDMA and GSM. An important point regarding the case of CDMA was the fact that a promising R&D target with possible first-mover advantages as well as a partner for collaboration were clearly identified with the help from the GRIs. This point indicates that there might also be a way for the government to give the private sector some help in coping with the problem of fluidity.

We see that the problem of technological uncertainty is to a certain extent associated with the ignorance about the trend or directions of recent research (know-what) in the technological areas concerned and about the distribution of worldwide R&D personnel and their expertise (know-who-knows-what). Then there is room for a contribution by the GRIs in keeping track of the research trends and personnel and in sharing this information with the private sector. This was exactly what was done by the ETRI in the case of CDMA development, who provided accurate assessment of the alternative technologies in wireless communication and identified Qualcomm as a target for partnership. Thereby, the ETRI contributed to reducing the unpredictability regarding the development of wireless communication technology. In this sense, we can say that government involvement can be helpful to the extent that, and only when, it can contribute to reducing technological uncertainty associated with identifying a promising R&D target.

Second, when the industry is characterized by a more predictable technological trajectory, the desirable form of government involvement can be either joint R&D or simply market protection, depending upon other aspects of technologies, such as cumulativeness, required size of R&D capital, or risks involved. When the industry is subject to less frequent innovation, such as in automobiles, the in-house R&D by private firms could handle R&D projects. In the case of automobiles, the Korean government provided domestic market protections, as well as export promotion measures to get access to foreign markets to achieve economies of scale. In contrast, there are industries, like D-RAM, that are characterized by high frequency of innovation and more risks. For these cases, we see more room for direct government involvement in the form of joint R&D. In other words, some differences between the D-RAM and automobiles in terms of the frequency of innovation seems to have resulted in different degrees of government involvement.

The above observations are consistent with the view that direct government involvement is better suited to handling the problem of cumulativeness (high frequency) than unpredictability of technological trajectory. However, even in the cases of government involvement in joint R&D to tackle the problem of cumulativeness, once the risk and financing problem is solved, the degree of government involvement should decrease so that private companies may take over. That was the case of D-RAM in Korea.[18] In this sense, we should emphasize again the importance of the in-house R&D conducted by private firms. In other words, when process innovation becomes more important, following the stage dominated by product innovation, it is natural for in-house R&D to take over because in-house R&D tends to be more effective in adaptation and improvement-oriented innovation. Of course, in general, even in the case of industries with a more predictable trajectory or less frequent innovation, we cannot deny the possibility of a positive contribution of direct government involvement in R&D: it might help to shorten the time required for catching-up.

However, there is an issue of the opportunity cost of the government resource involved, in consideration of the fact that the private sector alone can handle R&D projects of such a nature. Providing market protection and so on would be a less costly form of government involvement than direct R&D.

8.5.2 Importance of the Internal and External Knowledge Base and the Access Strategy: Policy Issue 2

We note the fact that leapfrogging occurred at the time of the technological paradigm shift, namely when new technologies had emerged. However, although new knowledge and technology tend to reside in public institutions, giving relatively easier access than otherwise (Perez and Soete 1988), this does not mean that they are in a state ready to be used in factories. "Development" or commercialization effort is still required in which the absorption capacity of the recipient firms or countries is critical. The case of CDMA development signifies the importance of the absorption capacity (internal knowledge base) of the Korean firms and GRIs in internalizing the external knowledge. On the other hand, emerging techno-nationalism does not simply mean that it is impossible for the latecomer firms to acquire needed technology and thereby catch-up and that the international technology market is a closed one. There were cases of "open techno-protectionism," as the examples of Hyundai Motors and Samsung Semiconductors show. These firms were able to get help from specialized R&D or venture firms. More important in this regard is the absorption capacity of the latecomer firms since this determines the detailed conditions of the technology transfer contract and the nature of the access.

We should also emphasize the importance of access to the external knowledge base, namely the issue of technology transfer. The experiences of consumer electronics, PCs, D-RAM, and mobile phones all indicate the importance of access to the external knowledge base when indigenous development of technology is difficult given higher frequency of innovation and higher fluidity of technological trajectory. Up to a certain point in their development, consumer electronics and PCs were able to catch-up market shares as the leading companies provided already mature technology in the form of licenses. However, as licensing became difficult or expensive, their catching-up slowed or even stopped. In the case of CDMA development, the Korean firms got access to not mature but emerging technology with a license not from the leading company but from a venture company. Since the Korean firms' contribution in commercializing the original technology was important in the CDMA case, their technological position was more sustainable than in the case of PCs or consumer electronics.

In contrast, when the trajectory is more predictable and the innovation is less frequent, the strategy in getting access to foreign technology may well be different. The often discussed example is the contrasting experience of Hyundai and Daewoo automobiles (K. Kim 1994; L. Kim 1997a). As is well known, Hyundai did not share management control with any of its shareholders, including Mitsubishi, and took sole responsibility for key R&D projects such as engine development. With help from specialized R&D companies like Ricardo, Hyundai's technological capability grew in a steady manner. In contrast, although Daewoo shared its management with General Motors (GM), Daewoo's perception was that GM was reluctant to transfer core technologies to Daewoo. Thus, this company experienced management conflicts among its major shareholders, and finally Daewoo separated from GM to become independent in the early 1990s. Only after this independence, and since the mid-1990s, has Daewoo begun to realize achievements from its own R&D effort. This experience suggests that just following the FDI strategy from beginning to end is not likely to generate a stage-skipping or path-creating catching-up. However, it should also be noted that having once arrived at the higher stage of technological development, the catching-up firms might want to form international alliances or even JVs to cope with the increasingly fierce global competition and to keep ahead. It is our opinion that several Korean firms have now reached this stage, and the old standing-alone strategy might not be effective any more. Daewoo Automobiles itself is now again actively seeking international alliance with foreign car makers including GM. This strategy might work fine this time since Daewoo now commands higher technological capability than before, which affects its bargaining position. In other words, the existing technological capability and base of local firms matters since they determine the concrete terms of the technology-related contract between the local and foreign firms.

8.5.3 Remarks on Further Technological Development of Korean Industries

We have attributed the difficulties of Korean firms in PCs and audio components to the peculiar nature of the technological regimes of these industries, especially uncertainty, and warned against any direct involvement by the government. Given this, what can governments do? Should they give up on these industries? Should the government stay idle and do nothing? In these industries, our warning is primarily concerned with government involvement in terms of direct R&D, and actually in these industries all R&D projects are currently private initiatives and there is no direct government involvement. This does not mean that the government cannot participate in other ways. As discussed above with CDMA as an example, the government or the government research institutes (GRIs) can contribute to coping with the problem of fluidity by keeping track of the research trends and personnel and in sharing this information with the private sector. Furthermore, we should note that because a path-following catch-up in these industries would not work or would take forever, the critical issue is how to generate stage-skipping along the path-following catch-up or an alternative path. Given that the private sector alone cannot deal with this problem successfully, we should approach the problem from the perspective of a sectoral or national innovation system that requires coordination among the firms, government agencies, and academia. To generate stage-skipping or an alternative path, what is needed is more "creativity." Here comes the importance of the universities as suppliers of creativity, and of the financial system as a supporter of creativity (new business ideas). In this regard, one great achievement by the Korean government was the establishment of the KOSDAQ stock market, like NASDAQ in the US. Only two years after its establishment, KOSDAQ has emerged as the mother of hundreds of small and medium-sized venture companies and startups. Many ambitious youths are joining KOSDAQ firms from universities and many talents are leaving the giants conglomerates (chaebols) to join these new styles of firms. Having financed their investment from stocks rather than from the banks like the chaebols, these new and flexible firms are better suited to handle the problem of uncertainty than the big and rigid chaebols. Actually, Sambo Computer Co., the rising star in PCs, is an outgrowth of an originally small venture company. This new phenomenon tells us what the government can do in the area of a national innovation system to deal with uncertainty-related problems.

8.6 CONCLUDING REMARKS

It is not easy to spell out in any simple manner the conditions for a technological catching-up or its failure without the risk of oversimplification. The conditions differ between different industries facing different technological and market conditions. The process is an outcome of a complex interplay of in-house R&D, the government, modes of technology transfer, market conditions, absorption capacity, and the nature of the technology or knowledge itself. What we have done is a first step toward some generalization drawing on the experiences of the Korean industries. The Korean experiences suggest that a path-following or stage-skipping catching-up is more likely to be undertaken through private initiatives in industries where innovations are less frequent or cumulative and the innovation path is more predictable, and thus the catching-up target is more easily identified, whereas a path-creating catching-up is more likely to happen through a public–private collaboration where the involved technology is more fluid and the risk is high with bigger capital requirements.

Malerba and Orsenigo (1995) and Breschi, Malerba, and Orsenigo (2000) have differentiated two kinds of technological regimes, namely a Schumpeter Mark I Pattern characterized by low technological opportunities, low appropriability, low cumulativeness, and less science-oriented knowledge base, and Schumpeter Mark II with opposite features. One might say that technological catching-up is more difficult in those industries belonging to the latter group since it is characterized by a high degree of concentration of innovative activities, high stability in the ranking of innovations and low relevance of new innovations. But, the process of technological catching-up is more complicated than this. Industries evolve and their technological characteristics also change depending upon the stages in the life cycles. If we take into account the issue of leapfrogging, things are getting more complicated. While Malerba and Orsenigo (1995) classified road vehicles and engines, telecommunications, and semiconductors as belonging to the Schumpeter II group, these are three industries where Korean firms achieved substantial catching-up or leapfrogging, although this does not necessarily mean that it will happen in other countries, too.

In this light, one might want to say that these Korean cases are more the exception rather than the rule. Such a consideration brings back the issue of organizational selection such that different styles of firms show different degrees of fitness to different environments. For conglomerates, such as Korean chaebols, predictability of technological trajectory was very important as it made it easy for them to fix catching-up targets and concentrate all the resources they can mobilize on the projects. This is one important aspect of the technological regime which is particularly relevant in the context of catching-up and ignored in the literature on the Schumpeterian pattern of innovations centered on the experiences of the advanced countries.

NOTES

1. An exception would be Dahlman, Ross-Larson, and Westphal (1987) who recognized the idiosyncrasies of technology transferred and adapted locally.