Research Policy 30 (2001) 459–483

research policy

www.elsevier.nl/locate/econbase

Technological regimes, catching-up and leapfrogging: findings from the Korean industries ☆

Keun Lee [a,*], Chaisung Lim [b,1]

[a] Division of Economics, Seoul National University, Seoul 151-742 , South Korea

[b] Department of Management and Information Technology, Korea Christian University, San 204, Hwagok 6 Dong, Kangseoku, Seoul 157-016, South Korea

Accepted 2 February 2000

Abstract

This paper examines the experiences of selected industries in Korea to identify the stylized facts in the process of technological capability building, and thereby, to sort out the conditions for the catching-up to occur. To explain the process, we have built a model of technological and market catching-up. A special attention has been given to the question of whether there has been a case of leapfrogging in any industry in Korea and, if so, what are the conditions for its incidence. In our framework, we first measure the degree of catching-up in terms of market shares in the world. Then, we focus on catching-up in technological capabilities in explaining the different record and prospects of Korean industries in market catching-up. In the model, technological capability is determined as a function of both technological effort and the existing knowledge base. As determinants of technological effort, we look at the technological regimes of the industries, such as cumulativeness of technical advances, fluidity (predictability) of technological trajectory, and the properties of knowledge base.

Using this model, we explain the different technological evolution of the selected industries in Korea, including the D-RAM, automobile, mobile phone, consumer electronics, personal computer and machine tool industries. We find three different patterns of catching-ups, path-creating catching-up (CDMA mobile phone), path-skipping catching-up (D-RAM and automobile), and path-following catching-up (consumer electronics, personal computers and machine tools). We interpret the first two case of catching-up as "leapfrogging." Unlike the argument by Perez and Soete [Perez, C., Soete, L., 1988. Catching-up in technology: entry barriers and windows of opportunity. In: Dosi, et al., (Eds.), Technical Change and Economic Theory, Pinter Publishers, London.], we find that important R&D projects, except automobiles where only private

☆ Earlier versions of this paper were presented at various places, including the 1998 European Summer School on Industrial Dynamics held in Cargese, France, the Korean Economic Association 1998 Annual Convention, and a seminar for the Technology and Evolutionary Economics Research Group in Korea. The authors would like to thank two anonymous referees for their two rounds of detailed comments. The paper has also benefited from the comments by, or the discussion with Morris Theubal, Luigi Orsenigo, Dominique Foray, Greg Linden, Linsoo Kim, Joonghae Suh, Ji-Soon Lee, Chang-wook Kim, Ha-Joon Chang, Yong-ho Bae, and Min-gi Hong. The authors would like to thank Cynthia Little and Sharon Kim for editorial help. All remaining errors are ours.

* Corresponding author. Fax: +82-2-886-4231.

E-mail addresses: klee1012@plaza.snu.ac.kr (K. Lee), hotlim@mail.kcu.ac.kr (C. Lim).

[1] Fax: +82-2-600-2459.

0048-7333/01/$ - see front matter
PII: S0048-7333(00)00088-3

R&D was involved, involved both private and public capacities, and that entry was not driven by endogenous generation of knowledge and skills, but by collaboration with foreign companies.

Keywords: Technological regimes; Catching-up; Leapfrogging; Korean industries

1. Introduction

The rapid economic growth achieved by the newly industrialized economies (NIEs) since their independence after the Second World War, has generated a huge amount of research on the mechanism behind the economic take-off. While the main contrast in the literature has been the role of the government vs. markets in catching-up development (Amsden, 1989; World Bank, 1993; Chang, 1994), a somewhat different, technology-based view has also been suggested (Lee, 1997; Porter, 1990; Dahlman et al., 1985; OECD, 1992; Hobday, 1995; L. Kim, 1997a). Most of the technology-oriented views have focused on explaining how developing countries, including the NIEs have tried to catch up with advanced countries by assimilating and adapting the more or less obsolete technology of the advanced countries, which is consistent with the so-called product life cycle theory (Bae, 1997; L. Kim, 1980; Lee et al., 1988; Utterback and Abernathy, 1975; Vernon, 1966). In this view, catching-up is considered as a question of relative speed in a race along a fixed track, and technology is understood as a cumulative unidirectional process (Perez, 1988).[2]

However, more recently, it has frequently been observed that in the catching-up process, the latecomer does not simply follow the path of technological development of the advanced countries. They perhaps skip some stages or even create their own individual path, which is different from the forerunners. This observation is consistent with the emerging literature on leapfrogging. For example, Perez (1988) observes that every country is a beginner in terms of the newly emerging techno-economic paradigm, which implies the possibility of leapfrogging by latecomers like NIEs. The idea of leapfrogging is that some latecomers may be able to leap-frog older vintages of technology, bypass heavy investments in previous technology system, and catch-up with advanced countries (Hobday, 1995). The increasing tendency toward globalization and development of information technology makes the leapfrogging argument ever more plausible.

As a matter of fact, the stories of catching-up or leapfrogging have been diverse depending upon industries and countries. Reviewing the experiences of Korean industries, we notice that some industries have achieved a remarkable catching-up or leapfrogging and continue to have good prospects for the near future, whereas others are facing serious difficulties after a certain amount of catching-up. How can these differences between industries be explained? This is the central question of this paper. We examine the experiences of selected industries in Korea to identify the stylized facts in the process of technological capability building and, thereby, to sort out, if possible, the conditions for a catching-up to occur. We also build a model of technological and market catching-up. Special attention has been given to the question of whether there has been an example of leapfrogging in any industry in Korea and, if so, what were the conditions for its incidence. These are the important questions somewhat neglected in important works on the Korean industries, such as that of L. Kim (1997a). In other words, this work is an effort to go beyond the question of how the catching-up was possible onto the question of what are the generalizable conditions for the successful catching-ups and whether there are different patterns of catching-ups including leapfrogging.

In this endeavor, we pay attention to the technological regimes of specific industries. Breschi et al. (1998) argued that the specific way innovative activities of a technological sector are organized can be explained as the outcome of different technological regimes implied by the nature of technology. The idea of this paper is that technological regimes also affect the innovative activities of catching-up firms and, hence, the chance for successful catching-up. In our framework, we first measure the degree of catching-up in terms of world market shares. Then, we

[2] An exception would be Dahlman et al. (1987), which recognized the idiosyncrasies of technology transferred and adapted locally.

focus on catching-up in technological capabilities in explaining the different record and prospects of Korean industries in market catching-up. In other words, we posit that the different record of market catching-up has a lot to do with the degree of technological capability building. With this in mind, we build a model to explain the building of technological capabilities as a function of both technological effort and the existing knowledge base.

Using this model, we explain the evolution of the selected industries in Korea, including the D-RAM, automobile, mobile phone, consumer electronics, personal computer, and machine tool industries. We find three different patterns of catching-up, which are defined in comparison with the paths taken by forerunning firms in the advanced countries. The patterns include path-creating catching-up (CDMA mobile phone), path-skipping catching-up (D-RAM and automobile), and path-following catching-up (consumer electronics, personal computers and machine tools). Our interpretation is that the first two cases of catching-up may be considered as "leapfrogging." However, in contrast to the original argument by Perez and Soete (1988) that leapfrogging or new entry tend to be initiated by research activities of public R&D capacities, we find that with the exception of automobiles where only private R&D was involved, all the important R&D projects involved both private and public capacities. Also, unlike Perez and Soete (1988) we find that the entry was not driven by endogenous generation of knowledge and skills but by collaboration with foreign companies. We will also argue that consumer electronics and personal computers, which once achieved a rapid catching-up by "following the path" taken by the forerunner firms, are now experiencing setbacks primarily due to the continuing substantial gap in technological capabilities. Our model explains the persisting gap in terms of the technological regimes of the industries, which determines the degree of R&D effort by the latecomer firms.

In Section 2, the paper begins by proposing a conceptual framework and hypothesis. Section 3 examines the production and trade data showing the trend of market catching-up by Korean industries, as well as patent data showing the characteristics of industries and speed of technological catching-up. Based on the model developed in Section 2, Section 4 discusses the experiences of the six industries in Korea. Synthesizing the experiences of these various industries, Section 5 provides a summary of the experiences of the six industries and a discussion of policy-related issues.

2. The model of catching-up in technological capabilities and markets

The central question in this paper is, what are the conditions for catching-up by latecomer firms where catching-up is measured in terms of both "technological capabilities" and "market shares." The two types of catching-up, namely technological catching-up and market catching-up, are not identical but are related to each other. For example, the latecomer firms can increase their market shares without enhancing their technological capabilities by relying on imported technology combined with cheap local labor. In this case, the two catching-ups are separated. However, sustained long-term increase in market shares is very difficult if it is not accompanied by increases in technological capabilities. If these firms do increase their technological capabilities, they will find it more and more difficult and expensive to buy the technologies needed for higher level market shares. In this sense, the two catching-ups are inter-related. Among the many determinants of market competition, such as manufacturing efficiency, marketing, logistics, and so on, technological capabilities are one of the most important elements, and, at the same time, success in market competition can earn the firm the extra money needed for R&D investment.

Our interest in this paper is in both types of catching-up. Thus, we start with an examination of the trend of Korean shares in selected industries. It was found that some industries continued to increase their shares, whereas others suddenly suffered a loss in market shares after a long period of increase. The D-RAM, automobiles, and CDMA cellular phone industries belong to the first group, whereas the consumer electronics and the personal computer industries belong to the latter group. To explain the difference between the two groups in terms of market catching-up, we turn to the second type of catching-up, namely technological catching-up. In the first group of industries, the gap between the Korean and the world's best firms in terms of technological capabilities has been continuously reduced, whereas in the second group of industries, the gap, after some reduction, still remains substantial.

It is not easy to measure and compare the level of technological capabilities. There is no single good quantitative measure, including patents, and thus, commonly adopted alternatives are qualitative ones.[3] One rough criterion is the distinction between the following three stages, duplicative imitation, creative imitation, and innovation (L. Kim, 1997a). Another criterion is the distinction between the following stages, assembly, low-tech part development, high-tech part development, product design, and finally, product concept creation. In the case of the forerunner firms, they start with a new product concept and then develop parts, and finally, assemble them. However, in the case of the latecomer firms, typically in the case of "reverse engineering" by Korean firms, they started with the assembly production of imported parts, then developed low- to high-tech parts, and learned to design the existing products with some modification, and finally, reached the stage of the new product concept creation. Thus, we are going to adopt these identified stages as the measure of technological capabilities reached by the Korean firms, and we will investigate what makes the difference in terms of stages of catching-up.

Now, let us turn to a more important aspect of the model as described in Fig. 1. In our model, the technological capability of the firms is determined as an outcome of interaction of the available R&D resources and the amount of R&D effort (or technological effort). The available R&D resources, among other things, consist of the internal and accessible external knowledge base, as well as financial resources. The access can come in diverse forms including informal learning, licensing, FDI, strategic alliance, co-development, and so on.

The level of firms' R&D efforts depend on the probability of success of the R&D effort. Here, the success should be considered in terms of probability of the actual development of target products, as well as the expected marketability (competitiveness) of to-be-developed products. In other words, we are separating physical development of products from their success in markets, like the distinction between invention and innovation. Such separation is needed because the market success of the products is not guaranteed even if target product is developed. In general, firms will devote more R&D resource when they are sure of the linkage between more R&D input and more R&D outputs (product development).[4] The technological regimes come in as determinants of the expected chance for product development, whereas such factors as cost edge, product differentiation, and first-mover advantages come in as determinants of the expected competitiveness of the to-be-developed products. Finally, we consider the importance of firms' strategies and the role of the government, as these factors could also affect both chance for product development and market success, and also, directly affect firms' level of R&D inputs.

Breschi et al. (1998) argued that the specific way innovative activities of a technological sector are organized can be explained as the outcome of different technological regimes implied by the nature of technology. Our idea reflected in the model is that technological regimes also affect greatly the innovative activities of catching-up firms and, hence, the chance for successful catching-up. The technological regime is defined by the combination of technological opportunities, appropriability of innovations, cumulativeness of technical advances, and the property of knowledge base. We conjecture that as far as catching-up is concerned, not all of them are relevant. For example, for R&D activities by catching-up firms, appropriability of innovations and appropriability of innovations would have less importance,

[3] In the literature, the indicators of catching up has been productivity growth (Abramovitz, 1986) or growth rate of gross national product (GNP), per capita GNP, or income (Verspagen, 1993). In discussing the rapid catching up by the NIEs, OECD (1992) and World Bank (1993) used "export of manufactures" as an indicator of industrial growth. However, as you notice, they do not specifically refer to technological aspect of catching-up.

[4] This way to address the linkage is different from the approach to see whether higher chance for product development leads to more R&D input or not. The point is that uncertainty and cumulativeness of technology tend to make the firms not sure of whether their R&D input can bring in tangible results or not.

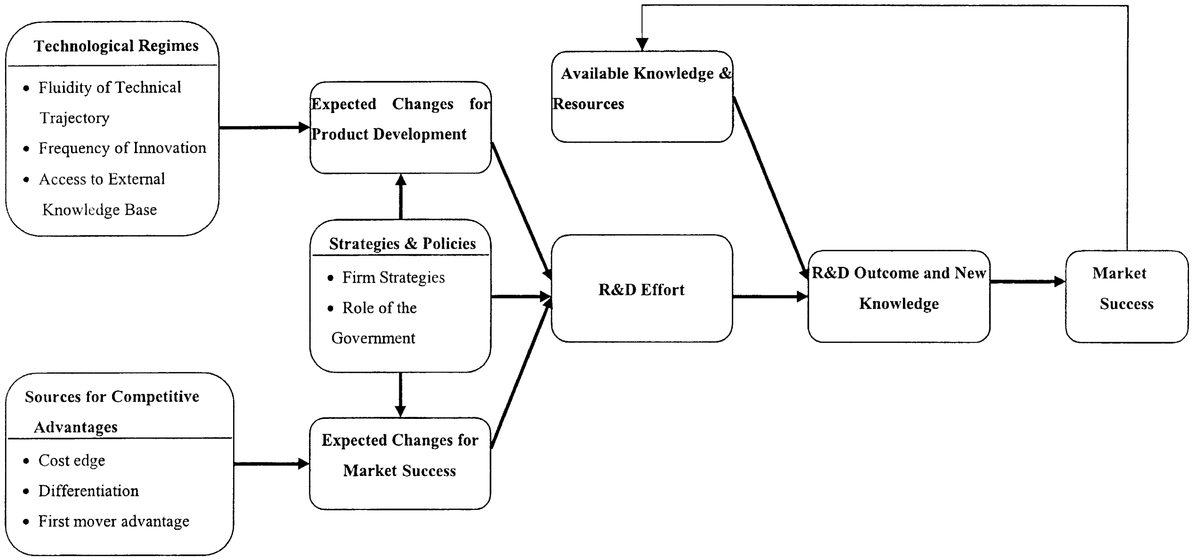

Fig. 1. Model of technological and market catch-up.

since in most cases of catching-up, they are trying to emulate the existing technologies.

Thus, we consider cumulativeness of technical advance as one of the important determinants of the chance for catching-up, and add a new element, namely the predictability of technological trajectory, as one of the important dimensions of the technological regime relevant for catching-up. We also take into account the degree of access to the external knowledge base (technology transfer) since it also affects the late-comer's R&D chances. Suppose we measure cumulativeness by the frequency of innovations, as in Breschi et al. (1998), then, we can say that the higher the incidence of innovation in a given period time, the bigger the R&D effort necessary for the latecomer firms. Next, the more fluid the technological trajectory, the more difficult for the latecomer firms to fix the R&D target. The fluidity of technological trajectory can be said to be higher when it is more difficult to predict the direction of future development of technology. For example, we consider D-RAM as featuring more predictable path of development as the industry evolves from, like, 1 kbit DRAM to 16 kbit and then to 64 kbit D-RAM, and so on. The fluidity often has something to do with the "year" of industry although this is not the sole or most important determinant of fluidity. In general, the trajectory can be said to be more fluid for emerging industry. This is consistent with the stylized fact that during the early life of the industry, there tends to be more product innovation than process innovation, and more product innovation tends to mean a wider range in future product development.[5]

We posit that the firms, after assessing the expected chance for product development as well as its market success, decide on the level of their R&D effort, namely the financial, human, and physical resource to be mobilized for the R&D projects. In this decision, there is an issue of selection of different organizational forms by different technological regimes.[6] Some firms would feel themselves more

[5] One might think that frequency and fluidity are equivalent. But, take D-RAM as an example of the industry with high frequency of innovation but low fluidity of technological path.

[6] We can also think of selection of different organizations by different types of market competition. For example, some firm would feel more suited in market competition dominated by cost edge than by quality differentiation or first-mover advantages. Actually, selection by technological regimes or market regimes is inter-related, and this is an important issue to be further explored. But, here, we focus on the former only since that is our interest and also, to a certain degree, market regimes can be derived from technological regimes.

fitted to an environment or industry with less frequent and more predictable technical change. For example, Swann and Gill (1993) show by simulation method that the more predictable the direction of technical change, the higher the market share by large multidivisional firms, and that the less predictable the change, the higher the market shares by small specialized firms.[7] The idea of organizational selection suggests that technological regimes determine the link between the R&D effort (input) and the expected chance for product development (output) of different styles of the firms. In this light, the discussion in this paper implicitly presupposes conglomerate style firms, like Korean chaebols. Then, we consider the following hypothesis that when the technological regime of an industry is featured by higher cumulativeness and more unpredictable technological trajectory, it is more difficult for catching-up to occur, by large conglomerate style firms in particular. We also examine the possibility that difficulty associated with cumulativeness or unpredictableness can be ameliorated by the access to external knowledge base and the role of the government.

Once R&D outcome (and the new level of R&D resources) of the latecomer firms in a certain industry is determined as an interaction of both R&D effort and the existing level of R&D capabilities (knowledge and financial resources), then, the new R&D outcome is combined with the firms' capabilities in manufacturing, marketing and logistics and so on, as parts of the value chain to produce a commodity heading for a test in the market.[8] The profits from the market success are, of course, a source of investment for future R&D, which thus constitutes one element of the firms' R&D capabilities (see the line connecting the market success box with the available knowledge and financial resources box in Fig. 1).[9] As Porter's so-called diamond model suggests (Porter, 1990), the determinants of competitive advantage of industries include the factor conditions, demand conditions, the conditions of related and supporting industries, and the firms' strategies and rivalries. To an important extent, the loss of market shares by Korean firms in such industries as consumer electronics and personal computers can be explained by referring to these factors, in other words, as rising domestic wages and weak clustering of related industries. In contrast, the focus in this paper is on the technological aspects of the story. While the escape from the current stalemate should be via more R&D effort to reduce the loyalty burden, differentiate their products, and to develop new products, the Korean firms have not had much success. We think that this has a lot to do with the nature of the technology of these industries.

In terms of the process of technological catching-up, we have identified three different patterns. Suppose that there exists a technological trajectory, or what we can call a path of development of technology. Each path or trajectory consists of several stages. For example, along the path of development of memory chips, we can perceive such stages as 1M D-RAM, 4M D-RAM, 16M D-RAM, and 64M D-RAM. Thus, here, the different stages correspond to different product innovations within a given series. Then, we can think of the following three patterns of catching-up as in Fig. 2.

First, there is a path-following catching-up, which means that the latecomer firms follow the same path as that taken by the forerunners. However, the latecomer firms go along the path in a shorter period of time than the forerunners. The second pattern is a stage-skipping catching-up, which means that the latecomer firms follow the path to an extent but skip

[7] C. Kim (1997a) investigates the issue of organizational selection in the D-RAM industry. The D-RAM industry used to be dominated by the specialized firms in its early days, and, later on, it soon changed to be taken over by the conglomerates from Japan and Korea. He argues that this has to do with the different fitness of different firms to the unique technological feature (environment) of the industry. Duysters (1996) also discusses the issue of the organizational types and the natures of the environment.

[8] During the high growth period before the 1980s, Korean firms mostly relied on manufacturing advantages using cheap and efficient labour to win the market. However, the potential of this strategy is being exhausted as new groups of latecomers adopt the same strategy with even cheaper labor. It is for this reason that the Korean firms are putting more and more resources into R&D.

[9] In this sense, market shares co-evolve with technological capabilities rather than being solely the results of such capabilities.

Path of the Forerunner: stage A --> stage B --> stage C --> stage D

Path-Following Catch-up: stage A --> stage B --> stage C --> stage D

Stage-skipping Catch-up: stage A ---------------> stage C --> stage D
(leap-frogging I)

Path-Creating Catch-up: stage A --> stage B --> stage C' --> stage D'
(leap-frogging II)

Fig. 2. Three patterns of technological catch-up. Notes: In stage C, the two technologies, C and C′, represent competing technologies.

some stage, and thus, save time. The third pattern is a path-creating catching-up, which means that the latecomer firms explore their own path of technological development. This kind of catching-up can happen when the latecomers turn to a new path after having followed the path of the forerunners, and thereby, create a new path. Among the three patterns, the first type is a more traditional pattern, while the latter two types contain some aspects of leapfrogging. Of course, the three patterns are not necessarily a once-and-for-all happening; there can be a mixed pattern. As a matter of fact, technological catching-up, more often than not, involves certain aspects of stage-skipping.

In Section 4, we will use the above-developed model to explain the processes of technological development in the six industries in Korea. Although the systematic explanation based on a model is the first object of this paper, the explanation also derives some stylized facts or hypothesis. Or to put it another way, the explanation can also be considered as an effort to prove the hypothesis. The hypothesis includes the statement that the less frequent the product innovation and the more predictable the technological trajectory are, the more likely is catching-up to occur when there is somehow an access to the existing external knowledge base to be combined with the indigenous knowledge base of the catching-up firms. In terms of the three patterns of catching-up, we will explain that the D-RAM and automobile industries involved the case of stage-skipping catching-up, and that the CDMA is a case of a path-creating catching-up.

3. The trend of market catch-up in the Korean industries and the technological characteristics

In this section, we examine the actual data from Korean industries to examine the trend of the market catching-up with a view to link the market share trend with the trend of technological capabilities. Then, Section 4 will investigate the trends of technological capabilities in six industries. First, Table 1 shows the trend of Korean shares in world exports in several industries. It is shown that those industries, which show steady increase of market shares, include automobiles, D-RAM, and mobile phones. For example, the Korean shares in passenger cars increased from a mere 0.63% in 1985 to 3.14% in 1995. The Korean shares in D-RAM increased from nil to almost 30% in the mid-1990s. Although not reported in the table, Samsung's shares in the US mobile phone market has reached 8% in 1997, and is expected to be around 13% or 14% by the end of 1998. It is interesting to note that the shares of Ericsson and Nokia producing TDMA phones are decreasing whereas those of Qualcomm and Samsung are increasing.[10] The pattern of a steady decline after a peak can be observed in audio components and digital computers. A dramatic setback is most clear in the case of computers, in which Korean shares declined from a 7.22% peak in 1989 to a mere 1.76% in 1995. Audio components show a steady decline after a peak in 1988. The case of machine tools is somewhat special in that Korean shares are increasing but very slowly, and their absolute level is still very low, less than 2%.

In Table 2, we examine the output and export values in the Korean industries. The period from the late 1980s to the mid-1990s is divided into two sub-periods, and growth rates are measured for com-

[10] It is reported that the top seller in the US mobile phone market is Ericsson with 41% share, followed by Nokia with 20% share, Qualcomm with 17% share, and Samsung with 8% share in 1997. Motorola followed Samsung, who caught up with it in 1997. Samsung's exported 450 000 units of mobile phones with a value of US$160 million, and expected to export about 2 million units by the end of 1998. A total size of the US mobile phone market was 5.63 million units in 1997. The above information is from Data Quest, reported in Mail Business News (98/8/31).

Table 1
Trend of Korean shares in World exports

	Passenger car (SITC 781)			Bus (SITC 783)			D-RAM		
	World exports	Korean exports	Korean share (%)	World exports	Korean exports	Korean share (%)	World exports	Korean exports	Korean share (%)
1983							1832	0	0.00
1984							3144	2	0.06
1985	82 743 193	518 789	0.63	2 750 846	4694	0.17	1367	19	1.39
1986	108 137 502	1 342 597	1.24	2 859 641	9054	0.32	1930	67	3.47
1987	127 503 028	2 748 395	2.16	3 818 551	24 110	0.63	2616	189	7.22
1988	140 420 047	3 336 160	2.38	6 376 695	27 179	0.43	6696	428	6.39
1989	145 505 897	2 048 352	1.41	6 276 777	17 382	0.28	9920	1086	10.95
1990	168 436 663	1 849 004	1.10	6 723 643	21 545	0.32	6413	1017	15.86
1991	172 190 341	2 123 890	1.23	7 755 190	50 891	0.66	6850	1452	21.20
1992	191 131 106	2 534 117	1.33	9 316 742	160 836	1.73	8515	2100	24.66
1993	184 500 730	3 883 985	2.11	9 023 787	256 072	2.84	14 320	3253	22.72
1994	206 018 872	4 470 416	2.17	12 109 504	279 057	2.30	20 993	5182	24.68
1995	230 630 527	7 241 992	3.14	16 600 979	363 650	2.19	39 442	11 426	28.97

	Machine tools			Audio component (SITC 763)			Digital computer (SITC 7522)			
	World exports	Korean export	Korean share (%)	World exports	Korean exports	Korean share (%)	World exports	Korean exports	Korean Share I[a] (%)	Korean share II[b] (%)
1983	8392.8	21.4	0.25							
1984	8537.0	21.6	0.25							
1985	9685.2	23.4	0.24	11 299 024	344 261	3.05	4 258 598	74 442	1.75	
1986	13 399.6	27.7	0.21	14 008 052	750 932	5.36	5 110 619	170 826	3.34	4.24
1987	15 196.8	37.5	0.25	13 506 320	1 207 850	8.94	6 823 530	297 193	4.36	5.44
1988	17 259.9	57.0	0.33	15 375 980	1 765 314	11.48	8 712 711	454 685	5.22	7.05
1989	19 216.1	80.5	0.42	14 969 626	1 633 147	10.91	8 683 563	512 449	5.90	7.22
1990	21 233.1	86.9	0.41	15 847 977	1 407 974	8.88	8 741 062	347 205	3.97	4.93
1991	18 754.2	95.4	0.51	15 854 698	1 544 356	9.74	9 074 423	482 542	5.32	6.40
1992	17 230.4	110.6	0.64	17 811 992	1 479 384	8.31	9 840 510	263 029	2.67	3.20
1993	15 209.6	110.5	0.73	17 916 888	1 581 845	8.83	10 886 193	344 863	3.17	3.74
1994	16 651.1	184.9	1.11	20 982 027	1 756 715	8.37		256 932		3.31
1995	21 396.1	334.3	1.56	21 765 275	1 824 208	8.38		169 351		1.76

Source: International trade statistics yearbook 1989, 1992, 1995.
Machine Tool Statistics handbook (1996–1997), Korea Machine Tool Manufacturers Association.

[a] Share I is share of Korea exports in world exports.

[b] Share II is share of Korea exports in world top seven country's exports.

Table 2
Trend of production and export values (US$ million; %)

	VCRs			Audio equipment			Personal computer			PC peripherals		
	Production	Exports	Share (%)	Production	Exports	Share (%)	Production	Exports	Share (%)	Production	Exports	Share (%)
1989	1797	1239	68.9	2524	1776	70.4	1735	973	56.1	1405	1294	92.1
1990	1567	1140	72.8	2569	1737	67.6	1325	633	47.8	1809	1531	84.6
1991	1770	1286	72.7	2693	1832	68.0	1446	721	49.9	1927	1750	90.8
1992	1691	1181	69.8	2572	1859	72.3	841	335	39.8	2770	2371	85.6
1993	1796	1310	72.9	2550	1912	75.0	955	381	39.9	3249	2704	83.2
1994	2025	1480	73.1	2697	2018	74.8	1249	296	23.7	3740	2856	76.4
1995	2120	1499	70.7	2958	1981	67.0	1389	223	16.1	5374	4188	77.9
1996	1937	1195	61.7	2367	1661	70.2	1376	159	11.6	6116	4963	81.1
Growth rate (1989–1993)	0.00	1.40		0.20	1.90		10.10	20.90		28.80	20.20	
Growth rate (1992–1996)	3.50	0.30		−2.10	−2.80		15.10	−17.00		24.00	20.30	

	Wireless communications			Passenger cars			Semiconductors			NC machine tools		
	Production	Exports	Share (%)	Production	Exports	Share (%)	Production	Exports	Share (%)	Production	Exports	Share (%)
1989	1733	485	28.0	856 133	364 835	42.6	4846.0	3179	65.6	251	48	19.1
1990	1602	489	30.5	964 603	338 968	35.1	7044.0	4459	63.3	276	43	15.6
1991	1672	514	30.7	112 8783	376 646	33.4	8101.0	5586	69.0	291	40	13.7
1992	1648	502	30.5	1 216 532	385 312	31.7	9740.0	6804	69.9	228	46	20.2
1993	1819	625	34.4	1 449 771	503 625	34.7	11 264.0	7026	62.4	272	41	15.1
1994	2091	697	33.3	1 645 453	586 008	35.6	19 116.0	12 984	67.9			
1995	2365	849	35.9	1 878 885	814 327	43.3	31 861.0	22 115	69.4			
1996	2432	848	34.9	2 108 846	1 008 929	47.8	22 504.0	17 843	79.3			
Growth rate (1989–1993)	5.70	6.60		15.30	13.00		25.40	17.20		2.10		
Growth rate (1992–1996)	12.10	14.00		14.70	27.20		27.60	27.30				

Source: Korea Development Bank, Korean Industry in the World 1994, Korea Development Bank Industry in Korea 1997.

parison between the two sub-periods. The consumer electronics and personal computers all show the slow down of export growth. This pattern is most clear-cut in the case of personal computers. During the 1989–1993 period, Korean PC exports grew at an annual average of 20.9%, whereas during the 1992–1996 period, annual growth reduced to −17.0%. This shows that the Korean PC industries discontinued exports and only served the domestic market as they lost their price competitiveness. Korean producers switched to the production of PC peripherals, such as monitors and disk drives. Exports of audio equipment also declined during the 1992–1996 period. Passenger car exports show a remarkable increase, namely from a 13% growth per annum during the 1989–1993 period to a 27.2% growth per annum during the 1992–1996 period. Thus, now, almost half of production is exported. A similar pattern can be observed in the case of semiconductors with more than 70% of the domestic production now being exported. The share of exports in total machine tool production is still very low, less than 20%, which is similar to the level of PCs and even lower than those of audio equipment and VCRs.

We interpret the above trends in terms of the model developed in Section 2, which defines market shares as a function of technological capabilities among other things. For example, the continuing increase of market shares in D-RAM is supported by the sustained increase of technological capabilities, whereas PCs have been losing shares as the one-time high market share was based only on cost advantage but had no solid basis of technological capability building. Increasing market shares in automobiles are supported partly by the increasing technological capabilities and partly by price edges, and their not-so-high market shares reflect the still significant existing gaps in technological capabilities. The same is true of machine tools where Korean firms are very slowly increasing their technological capabilities. One of the reasons for the lower market shares, compared to automobiles, is simply that cost advantages are less important for machine tools than for automobiles.

Above, our interpretation has been to relate the different stories of market catching-up to the different stories of technological catching-up. Now then, the next task should be to relate the different trend of technological catching-up to technological regimes. Although this will be mainly done in Section 4 presenting detailed qualitative studies of the six industries, before doing that, let us present here some informative figures on the nature of technological regimes of the different industries and one indicator of the relative degree of catching-up.

Patent statistics in Table 3 reveal some important characteristics of the industries. We note the four industries, which show a higher-than-average frequency of innovation measured by the number of patents. They are personal computers, D-RAM, consumer electronics, and sound and communication equipment. By contrast, in machine tools and automobiles, the number of the patents granted grew slower than the average. We think that this relative difference in the frequency of innovation is important in terms of catching-up possibilities as explained in Section 2. Another major characteristic of the industries is the fluidity of technological trajectory. In consideration of the product ages and the currently unfolding technological development, we take the technological trajectories of automobiles, machine tools and D-RAM to be less fluid than those of telecommunications, PC and consumer electronics.

Now let us see how the Koreans are doing in catching-up in these industries featured by the different degrees of cumulativeness and fluidity. Table 3 also examines the growth rates of patents granted in the US to the Korean firms and the whole world. Over the 1986–1993 period, US patents by Koreans grew at an annual average of 50.3%, compared to the 4.8% growth of the US patents in the whole world. We can take the difference between these two numbers as the speed of technological catching-up. The average speed of catching-up by the Korean industries is thus shown to be 45.5%. Let us compare these figures among the different industries. The two industries that display above-average speed of catching-up turn out to be D-RAM and sound and communication equipment. In all the other industries, the speed of technological catching-up is lower than the average. These figures imply that Korean catching-ups in these industries were supported more by cost advantages and less by technological capabilities. When cost advantages disappear, market shares plummet as in PCs and consumer electronics. In the case of automobiles, Korean firms are still maintain-

Table 3
World and Korean patent grants in the US: annual increase rates between 1986–1993

	Annual increase rate of US patents registered (a)	Annual increase rate of US Patents by Korea (b)	Speed of catching up $= b - a$
Whole industry	4.8	50.3	45.5
Machine tool	−0.9	38.9	39.8
Automobile	3.0	19.6	16.6
Personal computer	29.4	65.5	36.1
Dram	52.5	105.8	53.4
Consumer electronics	16.9	31.6	14.7
Sound and communication	8.2	103.4	95.2

Notes: (1) In the cases of personal computer, DRAM and consumer electronics, the US patents by Korea started to be registered from 1989. Therefore, the annual increase rate is between 1989 and 1993.
(2) In the cases of personal computer, DRAM and consumer electronics, the increase rate of the patent of the industry is measured by the increase of the number of patents which had a key word of "personal computer" or "DRAM" or "consumer electronics" in the title or abstract of the patents. It was assumed that the increase rate of the patents, which had a keyword of "personal computer" or "DRAM" or "consumer electronics," is the same as the increase rate of the patents in these industries.
(3) Degree of catching up was measured by deducting the annual patent increase rate in the US from the annual increase rate of US Patents by Korea
Source: (1) Data about machine tools, automobiles, sound and communication: US Department of Trade (1994) as cited in Lim (1997).
(2) Data about personal computer, DRAM, consumer electronics, sound and communication: patent data provided by US Patent and Trade Mark Office 1997.

ing cost advantages, which is the reason for the steady rise in market shares despite a slow catching-up in technological capabilities.

The above comparisons also present a challenging task, namely how to explain the different speed of catching-up in terms of the earlier hypothesis, as derived in Section 2, that the more fluid and frequent the technological change is, the more difficult technological catching-up will be. For example, how can we explain the fast catching-up in telecommunication despite its high cumulativeness and fluidity of technological regimes? Similarly, how about the D-RAM featured by high frequency of innovation? Section 4 will try to handle this difficult job by a more detailed analysis of each industry. As you notice, patent data presented above can serve only as a measure of speed of relative catching-up. But, it does not show how close to the forerunner the Korean firms have actually advanced in terms of technological capabilities. Since technological capabilities is more than that can be represented by patent data but also include both explicit and tacit knowledge, we have no choice but to rely on qualitative measures. As mentioned in Section 2, the primary measure of technological capabilities in this paper is a qualitative one, namely the stages in the reverse engineering the latecomer firms have reached.

4. The winning and losing stories of catching-ups

4.1. The automobile industry[11]

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 are less frequent concept changes. Frequency of innovation is also low. The property of knowledge base of automobile industry has such feature, 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. This is in contrast with PC parts

[11] This subsection draws on K. Kim (1994, 1997).

and peripheries, which 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 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 the R&D expenditure devoted to engine development was very 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 has 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 the 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 was basically the fruits of its own initiatives, without help from the government, which basically provided only the domestic market protection. Of course, 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 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 (K. Kim, 1997). 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 which 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, 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 middle-sized passenger cars, the localization ratio is higher than 90%, although core parts for luxury cars are still imported.

4.2. D-RAM industry

According to our model, technological regimes of the D-RAM industry is featured by high frequency of innovation and more predictable path of technological trajectory. While less uncertainty in technological trajectory means fewer handicaps for the latecomers, high frequency of innovation means more things to catch-up. Now, let us look into more details of this industry to see how it can give some chance for the conglomerate style firms like Samsung, especially late entry and market success chance 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, 16–64 Mbit chips, product innovation is oriented toward upgrading.[12] 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 (C. Kim 1997b). 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 shares 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 markets have evolved from the specialized firms from the large conglomerate firms such as Samsung (C. Kim, 1997a).

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.[13] Owing to their size as conglomerates with strong financial resources at hand, Korean firms, especially Samsung, have found it easy to enter this market.[14] 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 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 of sufficient size for the large conglomerate firms to be able to enjoy some of the advantages.[15] Late entry by the conglomerate firm after watching development was possible since it 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 of 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 DFI firms or private OEM with the facility provided by the foreigners (Bae, 1997). There was no systemic government help except some minor assistance from a government research institute (GRI) called the Korea Institute for Electronics Technology (KIET; now known as the Electronics and Telecommunication Research Institute (ETRI)). The period from the late 1970s to the early 1980s is the period of absorption of high-level technology and all 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 kbit 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 kbit D-RAM, but it was the decision of the private firms to skip the 1–16 kbit D-RAM to enter directly into 64 kbit D-RAM.

[12] In this sense, it might be said that it is competence-enhancing rather than competence-destroying if we use the terminology of Tushman and Anderson (1986).

[13] For a more technical treatment of this argument, see C. Kim (1997a).

[14] In this case, too, like the case of Hyundai's engine development, Samsung's chairman Lee Byung Chul's commitment to the D-RAM business made it possible for Samsung to devote enormous resources to this project.

[15] C. Kim (1997a) provided an excellent analysis of how the D-RAM industry evolved from being initiated by specialized firms in the beginning to being dominated by large conglomerates including the Japanese firms during the late stage, and also, he did simulation to prove this.

How was that possible? Access to the external knowledge base also holds the partial key to this question. The time that Korean firms, including Samsung, were considering the production of 16 kbit D-RAM was the transition period in the world D-RAM industry from 16 to 64 kbit. Samsung was able to buy 64 kbit 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 Instrument company. Thus, such stage-skipping catching-up was made possible by an 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 kbit memory chips in the mid 1980s. Samsung chose to develop its own design technology for 256 kbit or higher D-RAM as it was not easy to buy the design or it was not 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 was observed that Samsung's 256 kbit D-RAM by its Silicon Valley team turned out to be better than the Japanese counterparts (L. Kim, 1997b). After Samsung's independent development of 256 kbit D-RAM, some foreign companies were willing to sell Samsung their 1 Mbit D-RAM design technology, but Samsung refused to purchase since it thought it could develop it on its own (C. Kim, 1997a).

Government industrial policy always lagged behind the progress made by the private initiatives (Bae, 1997). 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 Mbit chips and finally, going to 256 Mbit chips. Development of 256 Mbit chips by the Korean firms was the world's first event, and in this sense, the Korean firms have now become a "path-leader" and the technological capability of the Korean firms has now reached the final stage of creation of new product concept and its design in the reverse engineering.

In summary, 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 the help from the government, overseas R&D posts, and returning brains from the USA.

4.3. Telecommunication industry: CDMA cellular phone

The development of the CDMA cellular phone system and the initiation of services in Korea is one of the most successful cases of a path-creating catching-up or leapfrogging, led by the private–public collaboration. When the Korean firms and the government authorities considered the development of the cellular phone system, the analogue system was (and still is) dominant in the USA, and the TDMA-based GSM system 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 the 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 also meant that 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 now) accounts 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, the telecommunication industry does not give the latecomers any incentives for the 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 trend and by identifying the correct R&D target that are more promising than the alternatives.

In achieving the leapfrogging by taking a different path, the role of the government was very critical in taking initiatives to form a R&D consortium with private firms and pushing them 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 MSM-electronic chip is imported. However, in 1997, ETRI succeeded in developing the MSM chip by itself,[16] and subsequently, Samsung declared in 1999 that it can now produce most of the core chips required in CDMA mobile phones. That means the completion of 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.

4.4. Personal computer[17]

The personal computer industry in Korea started with simple assembly in the late 1970s. Small venture companies, like Sambo and Quenix, manufactured the first time in Korea an 8-byte PC by reverse engineering. At that time, no foreign companies were interested in investing in the Korean market through joint ventures, and 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-byte PC after 1984, they felt the need to import higher technology by licensing since they realized it was very difficult to produce the 16-byte 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 joint ventures. 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 1985–1989 period was the best time for the PC firms in Korea, which emerged as the hottest site for the worldwide OEM production of PC 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

[16] Despite this development, Korean firms must continue to pay fees to Qualcomm due to the restrictions in the original contract. They are now to trying to revise the contract.

[17] This subsection draws on C. Kim (1997b).

OEM producers conducting 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 (K. Kim, 1997), 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 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 motherboard, memory chips, and other peripheral parts, such as HDD, dot printer head, laser printer engines, LCD, and CD-ROM drives. Nevertheless, they still had to import such items as most logic chips, HDD head, printer controllers, and LSU for laser printer engines.

Since the early 1990s, Korean PC industries have faced a sudden depression; exports have plummeted, and now, there are few PC exports from Korea, with an exception of Sambo 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 industry by 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. Secondly, we note the 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. Thirdly, the rising royalty was also a burden for assembly-oriented PC firms in Korea.[18]

Beyond the above-mentioned direct causes for the weakening of the PC industry, there were more important structural problems associated with 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 where technology or knowledge is more explicit. This feature makes the catching-up more difficult as the latecomers rise up the ladder. The PC industry is featured by very high frequency of innovation, and, furthermore, the concept change is frequent, and thus, it is very difficult to predict the direction of future product development. 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 MPU generations or technological trajectory will render the development by latecomers of the MPU useless or out-of-date. For example, it is reported that Intel and TI have recently 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 to develop PC was possible because they identified a target product which meets the market trend. However, after that, the continuous changes in products and market conditions have made such arrangement ineffective. In other words, given the high unpredictability, the latecomers cannot target future development items with any certainty. Actually, this is a problem that requires help from the other components of the national innovation system, such as universities and GRIs; the network between firms and academia is

[18] Some people say that with a large number of small firms in Taiwan, it is more difficult to impose on them royalties, whereas with a few large conglomerates, it was much easier.

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, the 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 pre-occupied with the price competitiveness of the final goods.

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

4.5. Consumer electronics: audio and video equipment [19]

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, only second 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 is related to the erosion of competitiveness of Korean products in the world markets, Korea being somewhat sandwiched between the advanced countries and the next tier NIEs. Thus, since the 1990s, Korean producers have been putting more emphasis on the domestic markets, modifying their products to capture Korean-specific tastes and demands.

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 investments, and Koreans were able to learn from their joint venture partners. As foreign investors gradually lost their interests in their Korean business owing to the export-oriented government policies and continuing restriction of domestic markets, the Koreans took over the business and began independent production from the late 1970s (Y. Kim, 1997). Thus, the channels of technology transfer changed from the informal learning from partners to the 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 reliance on the economy of scale to maintain price competitiveness. The second step in the duplicative imitation was the localization of generic-used 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 and not mature products, developed by

[19] This subsection draws on Y. Kim (1997).

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 are having difficulty in securing continuing access to external knowledge base while their own R&D capability has not grown sufficiently to make them stand alone. As they are getting closer to the forerunners and demanding more advanced technology, the forerunners in the advanced countries become 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% (Y. Kim, 1997, p. 427).

Why is it so difficult to acquire innovation capability or why are the Korean firms not putting enough money into R&D in this field? This answer had to do with the technological regime of the industry. Here, we have to take note of the changing nature of consumer electronics industry. Consumer electronics has increasingly become science-based rather than supplier-dominated as in the past. The trend is that the product life cycles are getting shorter and shorter, which means higher frequency of innovation and increasing technological uncertainty. Lacking the capability to lead the product innovation, the Korean firms are just busy in adapting and imitating successive appearance of the new products developed by the forerunning firms. Since they cannot be sure of the chance for market success of their own to-be-product, they cannot put strong R&D effort either; they can enjoy neither stable cost margin nor reliable quality differentiation.

Since the 1990s, as technology licensing is getting more difficult, Korean firms, like Taiwanese firms, have 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 have turned more to domestic markets, and their "product innovations" have mostly been adaptive ones to capture Korean tastes. For example, LG developed a refrigerator, which is especially suited to storing Korean foods. Of course, this means 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.

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 machine tool industry used to be featured by a relatively low frequency of innovation and low fluidity of technological trajectory although 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. It has something to do with the fact that the expected chance for market success of developed products has been perceived as rather low because they cannot expect safely any of 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 simply by 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 the observation on the special property of the knowledge base of machine tool industry. In the machine tool industry, the important knowledge about production 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.[20] 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 the 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, provides 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 the 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 NC device industry, let alone the factor of the weak interface with the customer firms and weak development of small- and medium-sized firms (Lim, 1997).

[20] This is because the knowledge for developing products and production machines are mainly tacit, therefore, formal education or training will not decrease the time needed for learning.

In general, the difficulties of late-comer firms, like Korean firms, have to do with both the tacit and explicit aspects of the technology. However, with the shift from specific-purpose machine tools to the generic-purpose machine tools and, furthermore, with the rise of NC machine tools, the importance of explicit core technology increased. In particular, the emergence of computerized numerical control (CNC) machine tools has given more importance to electronic know-how than to the skills embodied in the engineers (Ryu, 1997). As the machine tool industry absorbed the technology from mekatronics, product innovation has occurred more often, resulting in life cycles being shortened. In terms of core technology, such as the NC device, which accounts for the largest share in the total value of the NC machine tools, only 30% of the domestic NC machine tool products use the locally made NC devices (Ryu, 1997). 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 (Ryu, 1997). 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.

4.7. The model and the three patterns of catching-up in the six industries: summary

We have explained above 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 evolution of the six industries.

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

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

Second, we classify D-RAM as industry with high cumulativeness (high frequency of innovation) and more predictable trajectory. Thus, we must say that incentives for R&D effort is mixed for latecomer firms, but for the Korean firms with conglomerate structure, the expected chance for market success based on cost edge was perceived to be great, and the Korean firms were able to purchase production facility and product designs during the initial stage. Thus, given a predictable technological trajectory, the Korean firms, in collaboration with the GRIs, poured enormous amount of R&D inputs 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 1 to 4 Mbit, tended to make each successive round of the required investment bigger and bigger, and occurring at an increasing speed. Also, critical was the access to the external knowledge base in the form of reverse brain drain and overseas R&D posts. Now, the Korean D-RAM industry has reached the final stage of technological development, namely the creation of new product concept and design.

The 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 does not give the latecomers any incentives for R&D effort. However, this difficulty was ameliorated since the Korean R&D consortium gained access to the external knowledge base by the 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 trend and by identifying the appropriate target for R&D project 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 endogenous generation of knowledge and skills, but by collaboration with foreign companies. Anyway, the Korean firms have now reached the stage of creating and designing new products in terms of the stages in the reverse engineering.

Now, let us turn to the cases of consumer electronics and PC, 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 PC 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 has a lot to do with the technological regimes of these industries featured by the high frequency of innovation and high fluidity of technological trajectory. In these industries, important production, as well as design technology, tend to be embodied in core information technology (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 cannot enjoy the benefit from either costs 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 efforts. Thus, in these industries, even the 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 limited its role to providing protection for domestic producers. In these two industries, technological capabilities of the Korean firms are still somewhere between the stages capable of developing core parts and designing their own but imitative products.

Finally, the machine tool industry is a somewhat unique case. 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 expect safely any of 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 and presented in a table form below, although we are concerned with possible misleading owing to its very simplified nature.

5. Several policy-related issues

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 tacit knowledge 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 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 includes joint R&D with the private sector to conduct the 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 the 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 the “fundamentals,” based on which other policy or institutional variables act. In addition, we allow another “fundamentals,” that is, market competition. In other words, the 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. Then, 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 had better be limited to providing market protections of fixed duration. We think that in the cases of PC and consumer electronics, direct government involvement in R&D would not be effective or at least too costly in overcoming fundamental technological uncertainties. The story of short-lived public–private R&D consortium in PC can be an example in revealing the limits of such 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 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 concerned technological areas and about the distribution of worldwide R&D personnel and their expertise (know-who-knows-what). Then there is a room for contribution by the GRIs in keeping track of the research trends and personnel and in sharing this information with the private sector. This is what is exactly done by the ETRI in the case of CDMA development, which provides accurate assessment of the alternative technology in wireless communication and identified the 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 the government involvement can be helpful to the extent that, and only when, it can contribute to reducing technological uncertainty associated with identifying promising R&D target.

Second, when the industry is featured by more predictable technological trajectory, the desirable form of the government involvement can either be joint R&D or simply market protection, depending upon the 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 automobile, the Korean government provided domestic market protections, as well as export promotion measures to get access to foreign markets to achieve economy of scale. In contrast, there are industries, like D-RAM, that is featured by high frequency of innovation and more risks. For these cases, we see a 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 seem to have resulted in different degrees of the government involvement.

The above observations are consistent with the view that the direct government involvement is better suited to handle the problem of cumulativeness (high frequency) than the 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.[21] In this connection, 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 more predictable trajectory or less frequent innovation, we cannot deny the possibility of 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 opportunity cost of the government resource involved, in consideration of the fact that the private sector alone can handle R&D project of such nature. Providing market protection and so on, would be a less costly way of government involvement than direct R&D.

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 or know-how had emerged. However, although new knowledge and technology tend to reside in the public institutions giving relatively easier access than otherwise (Perez and Soete,

[21] In this regard, of course, there is an issue of timing of the retreat of the government so that too early disengagement may not jeopardize the stable growth of the industries. Actually, this issue of the length of infant stages is a controversial issue in the literature.

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 the 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 the needed technology and thereby catch up, and that international technology market is a closed one. There were cases of "open techno-protectionism," as the examples of Hyundai Motors and Samsung Semi-conductors show. These firms were able to get help from the 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 nature of the access.

We should also emphasize the importance of access to the external knowledge base, namely the issue of technology transfer. The experience of consumer electronics, PC, D-RAM and mobile phones, all indicates the importance of access to the external knowledge base when indigenous development of technology is difficult given a higher frequency of innovation and a 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 the CDMA development, the Koreans firms got access to not mature, but emerging technology, with the license not from the leading, but from a venture company. Since the Korean firm's contribution in commercializing the original technological was important in the CDMA case, their technological position was more sustainable than in the case of the 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 the sole responsibility of key R&D projects such as engine development. With the help from the specialized R&D companies like Ricardo, Hyundai's technological capability grew in a steady manner. In contrast, although Daewoo shared its management with 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 the 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 joint ventures 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 anymore. Daewoo Automobiles itself is now again actively seeking international alliance with foreign carmakers including GM. This strategy might work fine this time since Daewoo now commands higher technological capability than before, which affects its bargaining positions. In other words, the existing technological capability and base of local firms matter since they determine the concrete terms of the technology-related contract between the local and foreign firms.

5.3. Remarks on further technological development of Korean industries

We have attributed difficulty of Korean firms in PC and consumer electronics to the peculiar nature of technological regimes of these industries, especially uncertainty, and warned against any direct involvement by the government in these industries. Then, what can they do? Should they give up these industries? Despite this situation, should the government stay idle and do nothing? In these industries, our warning is primarily concerned with the 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 GRIs can contribute to cope 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 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 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 idea). In this regard, one great achievement by the Korean government was the establishment of the KOSDAQ stock market, like the NASDAQ in the USA. 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 the firms. Having financed their investment from stocks rather than from the banks like chaebols, these new and flexible firms are better suited to handle the problem of uncertainty than the big and rigid chaebols. Actually, the Sambo Computer, the rising star in PC, is an outgrowth of an originally small venture company. This new phenomenon tells what the government can do in the area of national innovation system to deal with the uncertainty-related problems.

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 over-simplification. 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, the 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 skipping catching-up is more likely to happen largely by 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 by 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 et al. (1998) have differentiated two kinds of technological regimes, namely Schumpeter Mark I Pattern featured 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 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. Although Malerba and Orsenigo (1995) classified road vehicle and engines, telecommunications and semiconductors as belonging to Schumpeter II group, these three industries, however, are exactly where Korean firms achieved substantial catching-ups or leapfrogging, though this does not necessarily mean that it will also happen in other countries.

In this light, one might want to say that Korean cases are more of the exceptions rather than the rules. Then, such consideration brings back the issue of organizational selection, such that different styles of firms show different degrees of fitness to different environments. For conglomerates, like the Korean chaebols, the predictability of technological trajectory was very important as it makes them easy to fix catching-up targets and concentrate all 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.

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