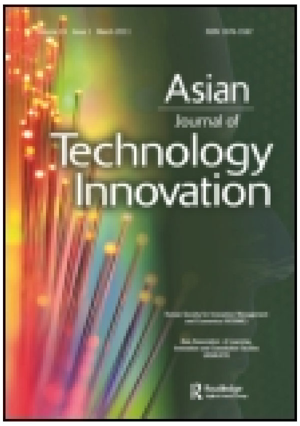

Asian Journal of Technology Innovation
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rajt20

Making a Technological Catch-up: Barriers and opportunities

Keun Lee [a]
[a] Economics Department, Seoul National University, Seoul, 151-742, Korea E-mail:

Version of record first published: 24 Feb 2011.

Asian Journal of Technology Innovation 13, 2 (2005)

Making a Technological Catch-up: Barriers and Opportunities[1)]

Keun Lee

Economics Department, Seoul National University, Seoul, 151-742 Korea
(kenneth@snu.ac.kr)

Summary

This paper has discussed several issues regarding the barriers and opportunities for technological catch-up by the late-comer countries and firms. As one of the barriers to technological catch-up, the paper emphasizes the uncertainty involved with the third stage of learning how to design. The barriers arise because as the forerunner firms refuse to sell or give license to successful catching-up firms who thus have to design the product by themselves. The paper discusses how to overcome this barrier. It also notes that if the crisis of design technology is a push factor for leapfrogging, arrival of new techno-economic paradigm can serve as a pull factor for leapfrogging, serving as a winder of opportunity. The, it emphasized the two risks with leapfrogging, namely the risk of choosing right technology or standards and the risk of creating initial markets, and how to overcome these risks. It discusses how to overcome these risks in leapfrogging, and differentiates diverse forms of knowledge accesses.

Then, the paper takes up the issue of whether there can be a single common or several models for catch-up. A common element of catching-up is to enter new markets segments quickly, to manufacture with high levels of engineering excellence, and to be first-to-market by means of the best integrative designs. This observation is supported by the fact that Korea and Taiwan has achieved higher levels of technological capabilities in such sectors as featured by short cycle time of technology. The possibility of two alternative models for catch-up is also discussed in terms of the key difference between Korean and Taiwan, especially in the position toward the source of foreign knowledge and the paths taken toward the final goal of OBM. Taiwan followed the sequential steps of OEM, ODM and OBN, in collaboration or integration with the MNCs. Korean chaebols jumped from OEM directly to OBM even without consolidating design technology.

Key words: technological catch-up, leapfrogging, OEM strategy, Korea, Taiwan

---

1) This paper draws from a longer paper that was presented at the 2005 Asialics Conference, held in Jeju, Korea, April 2005. This research is supported by the LG Yonam foundation.

1. Introduction.

While many appreciated the rapid economic growth achieved by the newly industrialized economies (NIEs) (Amsden, 1989; Chang, 1994; World Bank, 1993), more recent concern has been why such catch-up is not happening in other parts of the world. Despite huge amount of development aid and the accompanied policy changes, poverty and the gap between the rich and poor countries still prevails.

Argument has been made that even good policy prescriptions fail because of poor institutional conditions, such as insecure property right and rule of law and so on. Thus, the recent literature in economic development has debated on the relative importance among institutions, policy and geography as competing determinants of economic growth, with more research appearing in favor of the first factor, institution (Acemoglu, Johnson and Robinson, 2001; Rodrik, et al., 2004). Much missing in the debate on the determinant of economic development is the role of technology. Technological innovation is recognized as one of the most serious bottleneck in many countries, especially in middle income countries in Latin America. Furthermore, it is apparent that a stable macro-environment, secure property rights, adequate infrastructure, or liberal trade policy is not sufficient to trigger sustained growth.[2] While it still remains to be seen whether we should treat technology as a part of institutions or policy, there is also some shift in the technology-oriented views on economic growth.

The attention to the latecomers in economic development goes back to Gerschenkron (1962, 1963) that emphasized the advantages of the late comers, such as economy of scale in plant sizes in steel, owing to the fact that these countries started to use the technology only after it become matured enough to have the capital goods suitable for efficient production. However, the majority of the early literature 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 (Vernon, 1966; Utterback and Abernathy, 1975; L. Kim, 1980, 1997; OECD 1992; Dahlman Westphal, and Kim, 1985). 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). However, the speed of progress on the track has been uneven, with some catching-up rapidly and others lagging behind.

2) Specifically in recognition of this, the World Bank held recently a conference on "how to" of technological change and adaptation for faster growth in February 2005.

Regarding the sources of the uneven progress, one stream of research focuses on knowledge gap between the rich and the poor or the catcher and the laggard, and the issue of how to imitate, learn and create new knowledge in the latecomer country (Amsden, 1989, Amsden and Chu, 2003; Ernst and, Kim 2002; Ernst, 2002; Mathews, 2001; Yusuf, 2003). Applying the idea of knowledge creation and the concept of GPN (global production network) Ernst and Kim (2002) discusses how the late-comer firms learn the existing knowledge and create new knowledge. Mathews (2002; 2003) takes the resource-based view of the firm (Penrose, 1959) to analyze learning and competitive advantages of the late-comer firms.

On the other hand, a new brand of research points out that the catching-up paths taken by countries are different and there is an issue of policy choices among the alternatives. Lee and Lim (2001) has identified the three different patterns of catch-up: a path-following catch-up, which means the late-comer firms follows the same path taken by the forerunners, a stage-skipping catch-up, which means that the late-comer firms follows the path but skips some stage, and thus saves the time, and a path-creating catch-up, which means that the late-comer firms explores their own path of technological development. Then, some countries make quick progress and save time because they achieved some leapfrogging taking advantage of new techno-economic paradigm or skip some stages or even create their own 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 late-comers like NIEs. The idea of leapfrogging is that some late-comers may be able to leap-frog older vintages of technology, bypass heavy investments in previous technology system and catching-up with advanced countries (Perez and Soete, 1988). The increasing tendency toward globalization and development of information technology makes the leapfrogging argument ever more plausible as analyzed for the case of digital TV in Lee, Lim and Song (2005).

This paper takes up the important issue of why the catch-up is difficult or rare, and deals with both the opportunities and the barriers to catch-up. In explaining the sources of difficulties, it focuses on the difficulty of learning how to design the products or of acquiring the design capability beyond the production technology. We observes that while the later-comer firms go relatively easily with the early stage of catch-up by producing the goods designed by the forerunning firms in a factory designed by the forerunning firms (the so-called OEM, own equipment manufacturing), they, especially those who are successful, soon face difficulty as the forerunning firms someday refuse to sell or give license to them or move the production order to other lower-wage production sites. Then, they realized that they had to upgrade their design capability if they continue to hold the order or had to design the "imitative" product by themselves and start to sell them by themselves. This paper discusses how to overcome these difficulties.

The paper, however, notes that the crisis posed by design capability is also a window of opportunity for leapfrogging type catch-up ("stage-skipping" or "path-creating" catching-up), when the late-comer succeeds in designing their own products. While the existing literate has discussed the facilitating factors for leapfrogging, this paper emphasizes and discusses the two risks or uncertainty associated with the leapfrogging strategy, namely the risk of choosing right technology or standards and the risk of creating initial markets.

In section 2, this paper first starts with combining the three patterns of catch-up with the sequential pattern of technological development to identify four stages of technological catch-up, based upon the experience of the Korean and Taiwan firms. The stages are differentiated in terms of learning by the late-comers of 1) skills, 2) process technology, 3) design technology and 4) new product development. It is argued that the first and second stages largely correspond to the duplicative imitation and path-following catching-up, and that the third stage corresponds to creative imitation and stage-skipping catching-up and the final stage, to real innovation and path-creating or leading catching-up.

Section three discusses the nature of the third and crisis stage of learning how to design and how to overcome the difficulties by often achieving some leapfrogging. Section four discusses the push and pull factors for leapfrogging, and section five discusses the two risks with the leapfrogging and how to handle the risks. Noting that for every successful catch-ups access to foreign knowledge base, in whatever forms, is very critical, section six analyzes this issue of access to foreign knowledge base in details and suggests the sequential strategies for knowledge accesses along the stage of technological development and the roles of the government. The paper discusses and differentiates diverse forms of knowledge accesses, such as importation of equipment, licensing, FDI, co-development, overseas R&D outposts, scouting of key researchers, and international M&A.

Section seven summarizes the models of catch-ups with references to the experiences of Korea, Taiwan and China. The possibility of one single model is discussed in terms of some common features in catching-up process, and the possibility of two models for catch-up is discussed in terms of the key differences between Korean and Taiwan, especially in the position toward the source of foreign knowledge and the paths taken toward the final goal of OBM. Section eight concludes the paper with a summary.

2. Stages of Technological Development and Patterns of Catch-up

2.1. Combining the Theories

In describing the path of technological development of the late-comer firms, several stages have been identified in the literature. L. Kim (1997a) distinguishes the stages of technological development by dividing them into "duplicative imitation, creative imitation, and innovation stages".

Another series of stages can be discussed in terms of the OEM, ODM and OBM. For example, Mathews (2002; 2003) observed that the Taiwan firms have followed the steps of the OEM, ODM, and OBM. In contrast to the case of Taiwan, the Korean firms seemed to have followed the stage of OEM, OBM and then ODM as many of the Korean conducted the business with their own brand from an early stage of their development as the final assemblers but outsourcing most of intermediate goods. OECD (1996, p. 27) noted as follows, "Significant change occurred in the late 1980s. Many Korean export industries shifted from producing for OEM and began to market internationally under own brand names (OBM). Most of these goods were still standardized, of low quality, and cheap". Only after the drive to OBM export, they (Korean firms) realized that importance of product differentiation and quality improvement.

With somewhat different focus, Lee and Lim (2001) observed that in the case of the late-comer firms, they start with the assembly production of final goods using imported parts, then developed low- to high-tech parts, and then learned to design the existing products with some modification, and finally reached the stage of the new product concept creation. This is exactly the opposite to the process of product development by the fore-running firms which start with a new product concept and designs then develop parts for it, and finally assemble them. Thus, when one wants to know the level of technological development of the late-comer firms, one has to investigate which stage the firms has reached, for example, whether they are just assembling, making parts, or able to design the products themselves, and so on.

While we can identify different stages along the path of technological development, we can also see that there can be different patterns of technological catching-up (see table 1 below). Lee and Lim (2001) have identified the three different patterns. Supposing that there exist a technological trajectory consisting of several stages,[3] they conceive the following three patterns

---

3) For example, along the path of development of engine technology, we can perceive such stages as fixed line phone (or 1M D-RAM if in semiconductor industry), wireless phone (or 4M D-RAM), analog cellular phone (or 16M D-RAM), and digital cellular phone (or 64M D-RAM). Thus, here different stages correspond to different

of catch-ups. First, there is a path-following catch-up, which means the late-comer firms follow the same path taken by the forerunners. In this path following catch-up, catch-up means that the latecomer firms go along the path within a shorter period of time than the forerunners. The Second pattern is a stage-skipping catch-up, which means that the late-comer firms follows the path but skips some stage, and thus saves the time. The third pattern is a path-creating catch-up, which means that the late-comer firms explore their own path of technological development. This kind of catch-up can happen when the late-comers turns to a totally new stage while having followed so far a path experienced by the forerunners, and thus creates a new path. For example, Samsung's achievement in D-Ram can be considered as a case of stage-skipping catching-up. Without government help, Samsung, to produce 64 K bit D-RAM chips in the early 1980s. Government's position was such that Korean firms had to start from 1 K bit D-RAM, but it was private firms' decision to skip the 1 to 16 K bit D-RAM to enter directly into 64 K bit D-RAM. The time that Samsung was considering entering the production of 16 K bit D-RAM was the transition period in the world D-RAM industry from 16 K to 64 K.

Table 1 : Three Patterns of Technological Catch-up

Path of the Forerunner: stage A → stage B → stage C → stage D
1) Path-Following Catch-up: stage A → stage B → stage C → stage D
Eg.) Consumer electronics during analogue era, PC, Machine tools
2) Stage-skipping Catch-up: stage A ——————→ stage C → stage D
(leapfrogging I)
Eg.) Automobile engine development by Hyundai Motors
D-RAM development by Samsung
Digital Telephone Switch development by China (Mu and Lee 2005)
3) Path-Creating Catch-up: stage A → stage B → stage C' → stage D'
(leapfrogging II) Eg.) CDMA mobile phone,
Digital TV (Lee, Lim & Song 2005)

Notes: In stage C, the two technologies, C and C', represent alternative technologies.
Sources: Lee and Lim (2001), Lee, Lim & Song (2005), Mu and Lee (2005).

Combining the above discussions, we can consider the following stage of technological

product innovations within a given series.

development. The basic ideas are expressed in Figure 1. This figure integrates the stages of tech development and the patters of catching-up.

	Stage I	**Stage II**	**Stage III**	**Stage IV**
Stages in Catch-up	**Duplicative Imitation (OEM)**	**Duplicative Imitation (OEM)**	**Creative Imitation (Taiwan: ODM Korea: OBM)**	**Real Innovation (OBM)**
Patterns of Catch-up	Path-following	path-following/ stage-skipping	stage-skipping	path-leading/ path-creating
Learning Object	Operational Skills	Process Technology	Design Technology (for existing products)	New Product Development Technology
Learning Mechanism:	Learning by doing (production following manuals and guidance)	Learning by doing (production following product designs)	How to Learn? (crisis and switches to in-house R&D, R&D consortium, and overseas R&D outposts)	Co-development Strategic alliances

Figure 1 : Patterns of Catching-ups and Stages of Technological Development

According this figure, during the first stage, the late-comers learn (operational) skills by operating the plant imported from abroad but established in a late-comer country with the help of foreign producers. This stage corresponds to duplicative imitation and path-following catch-up. The second stage is to acquire process technology as the late-comer experiences setting up the factories and assembly line following the designed provided by the forerunning companies. This stage still mainly corresponds to duplicative imitation and a path following catching-up although there is a possibility for stage-skipping catching-up to happen. During the third stage, the late-comer firms become able to design imitatively the existing products or plants, often with the help of specialized R&D firms and personnel abroad. Since the designs which eventually developed by the late-comers are somewhat different, and often better than, from the existing ones by the forerunning firms, this stage can be considered as involving creative imitation and there is more possibility for stage-skipping catching-up to happen during this stage. Finally, the late-comer firms become able to conduct real innovation of creating a new product, which are the cases of path-creating or path-leading catching-up.

The main message this paper is trying to suggest with the aforementioned stages of technological development is that while the progress up to the first and second stage is relatively easy and happening in most of developing countries, very few reaches beyond this to the third stage of learning how to design. Before elaborating this argument, let us first start with more explanation of the first two stages.

2.2. The Relative Easiness of Catch-up until the Second Stage: the OEM or FDI Firms

Learning Skills by Operating

During the first stage of technological development and catch-up, the catching-up firms learns skills or operational know-how while they produce the final products according to the foreign-supplied manual on foreign-made plants or production lines. In other words, there is a manual to follow during operation, and tacit knowledge (know-how and skills) is created during the process. Thus, the process can be called skill formation which leads to increase in productivity. This productivity increase through learning by doing is the main sources for the catching-up during this stage. In terms of catching-up patterns, this stage corresponds to path-following catching-up. In this stage, being a simple assembly production, the responsibility taken by local or late-comer firms or entrepreneurs for production tend to be small.

Examples can be found in the cases of Hyundai Motor's assembler agreement with Ford in 1968 for SKD production, as well as Samsung's start-up of D-RAM assembly factory in the 1970s in Korea. In the case of Taiwan, examples are the numerous fully foreign-owned or joint venture firms in TV industry during the late 1960s and the 1970s as they transferred know-how not just to joint venture partners but also to their local part suppliers (Amsden and Chu 2003, pp. 21-24).

Learning Processing Technology

The second stage to acquire processing technology means that the late-comer firms now take the responsibility for production. In this stage, the late-comer firms acquire processing technology while they produce goods according to designs provided by foreigners, usually final producers. The designs can be either those of the products or those of production facility or both. In any case, acquisition of processing technology means that the late-comer firms become capable of *setting up their own production facility and takes responsibility for production*.

Foreigners provide not only designs but often dispatch personnel to provide technical guidance in setting-up production facility and/or in producing the goods. In terms of the catching pattern, the stage still corresponds to a path-following catching-up as it basically tries to imitate the fore-running firms. Although there might be a possibility for stage-skipping catching-up to happen during this stage, even that can be basically "duplicative imitation" in terms of the framework by L. Kim (1997).

Examples of this stage include, first, path-following catching-up by Hyundai in its production of Pony in 1975 with licensed production of Mitsubish engine, and, second, stage-skipping catching-up by Samsung in its 64 k D-Ram development; Samsung bought 64 k dram design from microelectronics and copied production facility of the Sharp with help of a small company which also built the production facility of the Sharp before. As said before, Samsung decided to skip the 1 to 16 K bit D-RAM to enter directly into 64 K bit D-RAM despite advice from the government to start from 1 K bit D-RAM. In the case of Taiwan, many engineers used to working in foreign-owned television factory left the firm to start their own firms in related areas (Amsdend and Chu 2003, p, 23-24). Some were targeting local markets and others were OEM but both took responsibility for their own production with technology licensing agreement with foreign firms.

3. Unfolding of the Crisis: Difficulty of Learning How to Design

3.1. Problems with the OEM Strategy

During the previous stages, the fore-running firms provided product or process designs for the late-comer firms. However, as technological capabilities of the late-comer firms grow, there comes a time when they feels it increasingly difficult to buy or get license for the designs held by the fore-running firms who are concerned with the so-called "boomerang effects" of the transferred technology. In this sense, this stage can also be considered as a "crisis" (L. Kim 1998) for the catching-up firm.

As noted in OECD (1996, p. 27), in the late 1980s many Korean export industries shifted from producing for OEM and began to market internationally under own brand names (OBM). Most of these goods were still standardized, of low quality, and cheap. Only after the drive to OBM export, they (Korean firms) realized that importance of product differentiation and quality improvement. Exactly for this reason (lack of design capability), the early export drives by the Korean car producers in the US markets with its own brand had run into serious difficulties after initial success in the 1980s (Guillen, 2001). Thus, from the 1990s, the Hyundai Motors had to switch to the markets in emerging economies like Latin America, Eastern Europe and Southeast Asia to earn time for quality upgrading. Only from the 2000s, it gained meaningful momentum in the US markets. This indicates the risk of the own brand exporting without solid design capability. However, the dilemma is that just sticking to OEM is not a long term solution either. As the OEM experiences of other two automobile makers (Daewoo and Kia) in the 1980s shows, Just doing OEM exports does not automatically lead to bringing up in-house development and marketing capabilities (Guillen, 2001).

Consumer loyalty and brand-name recognition worldwide in turn requires knowledge-based asset (design capability) that are necessary to create cutting-edge products (Amsden and Chu, 2003). Thus, the latecomer firms had to obtain design or product development capability. However, acquiring design capability for product differentiation and product innovation was not easy or quite difficult, which is the common dilemma for both Korean and Taiwan firms.

Koran chaebols soon realized that the fore-running firms were no longer willing to give them designs, and thus this constituted the crisis stage in the dynamic path of technological development.

For the Taiwanese firms, the crisis unfold as the foreign vendor switched to other lower wage economies, like Malaysia, for their OEM orders as wage rate increased in Taiwan. They realized that they needed to have design capability to create their own and more lasting competitive advantages which would enable them to continue to hold the MNCs. Alternatively they have to enter into new technological segments swiftly. However, design capability is not easily acquired simply by the network of domestic producers or by continuing with the international subcontracting because both lacked autonomous, endogenous mechanism to generate advanced technology (Amsden and Chu, 2003, p. 77).

Korean chaebols tried to overcome this crisis, and some of them succeed actually, by cross-subsidizing a huge amount of R&D money among affiliates, and when even that was not enough, they had to form R&D consortium with the government. For Taiwan firms of smaller scale, the solution was the "new developmental state" with its import substitution policies. The late-comer state was the midwife of new industrial growth poles around which small firms could cluster, and it developed, in public research units like ITRI, part and components that were formerly imported and had the private firms to produce them (Amsden and Chu, 2003, p. 77).

3.2. Overcoming the Crisis: Active Learning and Big R&D input by the Business Groups or with Help from the Government.

The nature of the crisis is that there do exist the products for the late-comers to imitate but no design of them is available from the incumbent producers who are reluctant to transfer the design technology. Although design itself is not available, the late-comers are able to utilize tacit knowledge held by specialized R&D firms or individual scientist or engineers in the form of contracts, reverse brain drains, and/or overseas R&D outpost. Sometimes, the late-come firms had to rely on memory of R&D persons previously involved in R&D projects of the fore-running companies to imitate, although with some twist, the existing product design or concept. Of course, the late comers also have to rely on explicit knowledge existing in the form of the licensing, literature or other forms of public knowledge. In successful cases, the late-comers develop their own design of an existing product which is often better than existing design by the forerunners. In what follows, let us elaborate this process with four cases.

Hyundai Motors in Korea

The main business of Hyundai group was construction, and it entered automobile industry in the early 1970s by establishing a joint venture with the Japanese car maker, Mitsubish. The Japanese company provided engines and other key components, and Hyundai just assembled them. Hyundai was a licensed producer but not an OEM producer as it used its own brand in local market and also in exporting. However, when Hyundai wanted to develop its own engines, the 20% equity holding Mitsubish refused to teach Hyundai how to design and produce engines. Most developing country businessmen would have stopped there, but the founding chairman, Mr. Chung, did not stop there.

He decided to spend an enormous amount of the R&D expenditure devoted to engine development (Lee and Lim, 2001). Luckily, Hyundai was able to get access to the external knowledge of specialized R&D firms, like Ricardo Co. in England. Since its business was not to produce and sell the cars but to sell the technology itself, their attitude toward late-comers, like Hyundai, was different from that of car assemblers (K. Kim, 1994). This could be termed something like “open protectionism” such that although rising techno-nationalism is a fact, international technology markets are not yet tightly closed and there exist diverse business entities who are ready to transfer technology to late-comers if certain conditions are met (Lee and Lim, 2001). The process was not easy, and it was not just such that Ricardo provided the design of an engine and Hyundai just develop it according to the design. It was basically a co-development by the two entities as the final design was a totally new one. They had to try more than 1,000 proto types until they succeeded finally after 7 years after the first project year of 1984.

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 domestic market protection. Hyundai’s technological development also involved a process which can be classified as a stage-skipping catching-up in our framework (Lee and Lim, 2001). 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.

Samsung in Korea

In the 1970s, several Korean firms started wafer processing of memory chips in 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 KIET (Korea Institute for Electronics Technology; now known as 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 K bit D-RAM chips in the early 1980s. At that time, the government's position was said to be such that Korean firms had to start from 1 K bit D-RAM, but it was the decision of the private firms to skip the 1 to 16 K bit D-RAM to enter directly into 64 K bit D-RAM.

How was that possible? Access to the external knowledge base also holds the partial key to this question (Lee and Lim, 2001). The time that Korean firms including Samsung were considering production of 16 K byte D-RAM was the transition period in the world D-RAM industry from 16 K to 64 K. Samsung was able to buy 64 K bit D-RAM design technology from Microelectronic Technology, a small US-based venture company and manufacturing technology from the Japan-based Sharp (C. Kim, 1994). Thus, such stage-skipping catching-up was made possible by access to the external knowledge base in the form of licensing.

However, from the 256 kilo bit D-RAM, Samsung found that as it was not easy to buy the design of memory chips or it was not cheap to buy the design (L. Kim, 1997b). Thus, they decided to develop its own design technology for 256 or higher K Dram. In this process, the role of overseas R&D outposts in Silicon Valley and returning brains was critical. It is observed that Samsung's 256 k dram by its Silicon valley team turned out to be better than the Japanese counter parts (L. Kim, 1997b). After Samsung's independent development of 256 kilo bit D-RAM, some foreign companies offered to sell Samsung their 1 mega D-RAM designs, but Samsung refused to purchase since it though it could develop it on its own (L. 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 4M chips and going finally to 256M chips. Development of 256 M chips by the Korean firms was the world first event, and in this sense the Korean firms have now become a "path-leader" and their 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 sum, the case of D-RAM can be considered as a stage-skipping catching-up that relied upon access to the external knowledge base in the form of licensing and overseas R&D outposts and took advantage of the mass production and investment capability of conglomerate firms (Lee and Lim, 2001).

Electronic Calculator in Taiwan

Third, in the case of Taiwan, the era of electronic calculator with its peak in the mid 1980s signified a trend away from OEM toward ODM (original design manufacturing) which paved the way to notebook and cell phone in later period (Amsden and Chu, 2003, p. 28-32). Young, Taiwan educated engineers contributed to the rise of the industry since the 1970s by copying a design and making it a little different. Since the early 1980s the Taiwanese manufacturers mastered the skill of design integration, which enabled them to be the first to market (if not lowest in cost) and thus to win the most profitable original design contract from foreign prime contractors (ibid.). It is important to note that despite collaborative relations with foreign vendor acquisition of design capability required active learning effort from the Taiwan side. The Taiwanese engineers went around the world to study LSI (large-scale integration) applications, and eventually, by combining what they saw and what they learned from Japanese suppliers, they had become good at integrating into a small space a large number of parts and components sourced globally at the lowest prices (ibid.).

Laptop PC in Taiwan

Fourth, while the above is an example of acquisition of detailed design capability, acquisition of more fundamental design capability or the basic design platform, was possible with the help of the government research institute like the ITRI (Industrial Technology Research Institute). A notable example is the public-private R&D consortium to develop laptop PC which ran for a year and a half from 1990 to 1991(Mathews, 2002). This consortium with capital of less than 2 million US dollars developed a “common machine architecture” for a prototype which can easily translate into a series of standardized components that was produced by manufacturers through mass production. The consortium represented a water-shed, after some previous failures, indicating the potential of R&D consortium to help establish new “fast follower” industries (Mathews 2002).

4. Push and Pull Factors for Leapfrogging

4.1. Crisis Leading to Leapfrogging: the Push Factors for Leapfrogging

The preceding section emphasize the "crisis" or critical stage, such that the late-comer firms face difficulty in learning how to design products or plants whereas the forerunner firms refuse to sell or give license to them. However, this crisis can be a momentum for "stage-skipping" or "path-creating" catching-up if the late-comer firms overcome the crisis by diverse means, as noted in the examples in the preceding sections. .

4.2. Grabbing the Opportunity of New Paradigm: the Pull Factor for Leapfrogging

While the above discussion suggest that the pressure to have one's own design capability might lead to the happening of leapfrogging, emergence of new techno paradigm can also bring new opportunity for late-comer firms to exercise leapfrogging. The argument on the advantages of catching up countries goes back to Gerschenkron (1962, 1963) that emphasized the advantages of the catching-up countries, such as economy of scale in plant sizes in steel, owing to the fact that these countries started to use the technology only after it become matured enough to have the capital goods suitable for efficient production. However, this discussion was confined to the catching up in the mature technology. It is Freeman and Soete (1997) and Perez and Soete (1988) that apply the idea with focus on the role of the new technological paradigm which brings forth a cluster of new industries. It is observed that emerging technological paradigms serve as a window of opportunity for the catching up country, not being locked into the old technological system and thus being able to grab new opportunities in the emerging industries.

A new technological paradigm can be represented as technological trajectories at the level of a specific industry. A technological trajectory is the pattern of "normal" problem solving activity (i.e. of "progress") on the ground of a technological paradigm (Dosi, 1982). In the period of emergence of new technological trajectories, there can the disadvantage of the established firms and the advantages of the latecomers in adjusting to new technology (Christensen, 1997) If this new trajectory brings about architectural innovation through reconfiguration of the existing product technologies, it can also lead to advantage of the latecomers (Henderson and Clark, 1990).

Perez and Soete's argument on leapfrogging has an element of the product life cycle model (Utterback and Abernathy, 1975; Klepper, 1996) as they emphasize the advantages of early entry into the new industries, such as low entry cost. As conditions for successful entry by the catching-up economies, Perez and Soete (1988) look at the productivity capacity, human resources and locational advantages (distance to critical supplies and knowledge). The argument is as follows, for example. First, since the equipments to produce new industry goods are not developed yet, general-purpose machines should be utilized and production volume is small. Therefore the entry barrier associated with economy scale does not exist. Second, in the initial stage of new technological paradigm, the performance of technology is not stable and not parochial to a firm. Therefore, if there are only the human resources who could access the sources of knowledge and create new additional knowledge, entry into emerging technology can be easier than during the later stage of technological evolution. Third, catching-up countries can be said to be in a rather advantageous position as they are not locked into old technologies. The advanced countries tend to be locked into old technologies due to the sunk costs of their investment.

4.3. Rapid Technological Change leading to Leapfrogging type Catch-up

If we combine the push and pull factor for leapfrogging, we can reason that the path of "successful" technological development is likely to involve the incidence of leapfrogging and that is more likely to happen in the sectors characterized by rapid technological change or short technological cycles. Here, let us elaborate more by examining the two successful cases of catch-up, the Koreans and the Taiwanese.

Korea and Taiwan are the two most successful catch-up economies in the world. On the one hand, these two countries share some commonalities, on the other hand, there does exist important differences. Often noted is the difference in terms of the role of big versus small firms in each economy with Korean dominated by a few giant firms and Taiwan by a large of smaller firms (Christensen et al. 2001; Saxenian and Hsu, 2001), although Amsden and Chu (2003) note the increasing scaling up of the firms in Taiwan.

Despite the difference in diverse dimensions, Korea and Taiwan were facing basically the same problems in technological catch-up, which involves, even in high-tech industries, manufacturing products that are new to them but mature globally. While the private R&D of the first mover include basic or some applied research, that of the late-comer as the fast second mover is closely coupled with production and detailed design (Amsden and Chu, 2003, p. 163). The catching-up firm's task is to source their high-tech inputs from overseas and thereby create their scarcities in other inputs, design or functions when a "new" mature products is still hot (ibid.). Then, competitiveness of the catching-up firm depends on its ability to enter new markets segments quickly, to manufacture with high levels of engineering excellence, and to be first-to-market by means of the best integrative designs (ibid. p. 167). Thus, when product development at the world technological frontier is rapid, followers' high-tech activity booms. This prediction by Amsden and Chu is confirmed by quantitative analysis using the patent data of Korea and Taiwan by Park and Lee (2004).

This study is an econometric analysis to find which sectors tend to generate more catch-up by the firms from Korea and Taiwan. Here, catch-up is defined the growth rates of US patents registered by the two economies, and each sector is defined by the diverse elements constituting the technological regimes of the sectors. The regime elements include the often discussed in the context of advanced countries by Malerba & Orsenigo (1996) and Breschi *et al.* (2000) such as technological opportunities, appropriability of innovations, cumulativeness of technical advances, and the property of the knowledge base, but also the other set of elements newly proposed in the study, such as accessibility to external knowledge flows, uncertainty of the technological trajectory, knowledge gap, and technological cycle time

This study confirms that Korea and Taiwan has achieved higher levels of technological capabilities in such sectors as featured by short cycle time of technology whereas the advanced countries do significantly better in those sectors with longer cycle time. Short cycle time or faster change in technological knowledge permits technological niches and room to emerge for catching-up economies, thus promoting the building of technological capability by the late comers.[4] This observation is consistent with the findings by the Albert (1998), from his study on patenting trends in the US that Taiwan and Korea emphasizes fast commercialization of information technology as the patents by these countries show much shorter technology cycle time than those by Japan and cite less scientific literature.[5] Although what the late-comer firms developed is a new product, it was possible by applying the foreign sourced sciences and the seed technology to the specific development target. This point is similar to the leapfrogging argument by Perez and Soete (1988) and Freeman and Soete (1997), who argue that shift or emergence of new technological paradigms can serve as a window of opportunity for the late comers and can permit leapfrogging by developing countries.

4) Short technological cycle time is also found as the characteristics of Japan, Korea, and Taiwan in Albert (1998). He argues that there is marked acceleration of the TCT values for Taiwan in the automotive and information technology sectors and for Korea in the information technology sector.

5) The cycle time in patents means the median age in years of prior patents cited in the patents. See Albert (1998).

5. Two Risks with Leapfrogging

While the existing literate has discussed the facilitating factors for leapfrogging in terms of the three aspects of production capacity, human resources, and locational advantages, this study is rather to emphasize the following two risks facing the leapfrogging firms. The first kind of risk is that of choosing right technologies out of several alternative technologies or standards, and the second risk is how to create the initial market after the choice of technology to produce new goods.

5.1. Choice of Right Technology: the First Risk

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 as it provided 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.

The risk of choice of technology is sometimes mitigated when the technology is characterized by unique features such as the standards being fixed before markets. Examples are the case of CDMA technology and digital TV where the technological standard is fixed before the market is formed (Wallenstein, 1990; Cargill, 1989).

Initially standards for CDMA wireless communication and digital broadcasting system were established in the US or in the EU even before the market was formed. In the case of CDMA, the TIA (Telecommunications Industry Association) adopted CDMA as North American digital standard owing to Qualcomm's efforts in 1993 before any market toward CDMA communication is formed. In Europe, following a similar step, GSM was adopted as the standard in Europe. In Digital TV technology, the standard was formed by the so-called "Grand Alliance" in the US in 1993 and later evolved to be finalized by FCC in 1997. This is in contrast to what happens in traditional industries, such as automobile and other consumer durable goods, where the standard or the dominant design are established as a result of competition in the market

(Klepper, 1996; Clark, 1985).

Given the feature of "standards before markets", future technological trajectory can be assessed more easily even at an early stage of technological evolution. This feature tends to reduce the risk of the early entrants and hence the catch-up by the late-comers. What the catch-up firms, like Korean firms, should do was simply to develop products compatible with that standard although the details were more complicated than this.

5.2. Risk of Initial Market Creation

When the late-comer firms go along the path of leapfrogging, one of the risks should be how to create and maintain the initial markets and competitiveness. To tackle this risk, diverse methods have been resorted to, such as protection of local markets by the government regulations (import restrictions, tariffs, and quotas), procurement of national products and subsidies to exports and international marketing, declaration of some product technology as the national standards, and use of the segmented nature of local markets, as in the case of China.

While it has now become impossible with the WTO environment, the Korean government provided market protections to the local automakers when they went along the path of stage-skipping catch-up by developing their own engines adopting then-emerging technology of fuel injection type rather than the old and then-dominant technology of carburetor-type. In the case of CDMA development, private firms once argued for the existing European standards of GSM technology rather than trying to go along the uncertain and risk technology of CDMA. However, the government declared the CDMA as the national standards so that there may be a guaranteed market for the CDMA-based products.

Although some or many of the market protectionist measures are against the principle of fair market competition, one justification can be made by the fact that the incumbent foreign firms often charge dumping or predatory prices for exports (or imports to the late-comer countries) upon the new of successful development of key capital goods by the late-comers, whereas they have been charging high or monopoly prices to the same goods as there used to be no competitive suppliers in late-comer countries. Such cases are numerous between the Japanese firms exporting core parts and equipments to Korean assemblers and the Korean firms trying to localize such items. Thus, localizing catch-up is quite difficult as the to-be-developed capital goods should be of better quality and lower prices than the competing products by the advanced countries. Unless there is provide incentives or regulations for using the locally developed capital goods, other final assembler firms do not take the risk of switching from the verified foreign products to locally-made uncertain products.

In the case of digital automatic telephone switch locally developed by indigenous firms in China, the role of the government was decisive in their competition against the products by the foreign JVs in both rural and urban areas (Mu and Lee, 2005). The basic role of theChinese government was to provide market protection and to give incentives for the adoption and use of domestic products. In 1996, the government stopped arranging foreign government loans to import digital automatic switch equipment. Instead the Chinese government began to impose tariffs on imported communication equipment, to promote the purchase of locally-made equipment. The sum of the market share of local firms (including Sino-foreign joint ventures) was 63.1% in 1995. One year after tariffs on imported communication equipment went into effects, the figure reached 84.8% in 1996, and in 1997, reached over 90%, or 94.9%.

Since 1997, the MPT (ministry of post and telecommunications) had organized coordinating conferences every year with the Administrative Bureaus of Post and Telecommunication. Through these conferences, the MPT encouraged the Administrative Bureaus of Post and Telecommunication to purchase indigenous equipment, if the equipment were suitable in character and proper in price. These two coordinating conferences were a turning point for the growth of the communication manufacturing industry in China as they gave huge orders for Chinese firms like the Huawei (Mu and Lee 2005). Also, under the encouragement of the People's Bank of China, the China Construction Bank supplied indigenous firms a big amount of buyer credit.[6] Affected bythe coordinating conferences and financial support, since 1998 the market share of the indigenous firms increased rapidly, and they became the main suppliers in the domestic market (Mu and Lee, 2005).

Next, the issue of the initial market creation is related to the issue of appropriation of innovation outcomes. Appropriability of innovation outcome in IT is specially influenced by the standard settings (Lee, Lim and Song, 2005). Producers of the products adopting more dominant or successful technology standard can appropriate returns from R&D investment more easily than others. In this competition for standard setting, forming alliances, cultivating partner and ensuring compatibility are critical (Shapiro and Varian, 1998). Owing to the network externality, competitive advantage of my product depends not only on the performance and price of my products but also those of complementary products made by collaborative partner firms and governments

6) Including Zhongxing and other telecommunication manufacturing firms, the volume of buyer credit supplied by China Construction Bank was 8 billion RMB yuan in that year. From *Shenzhen Special Zone Daily (Sehnzhen Tequ Bao)*, July 30, 1998.

who share the same technological standards. Since cultivation of enough big market size earlier than others or rivals and the losses to the losers are substantial, the involved parties want to set the standard first before putting their product to markets and them under anarchic competition. Thus, isolated development without paying attention to the issue of standards might lead to a failure of the whole project. In standard setting, collaboration and getting partnership with rivals or suppliers of complementary products are important. Also important is who create and get to the market first as the size of the market determines the success or failure of one standard against other. Again, in this competition for standard setting and market creation, the role of the governmental can be noted as it can plays the role of facilitating the adoption of specific standards and thereby influencing the formation of markets at the right times.

6. Accesses to Foreign Knowledge and Catch-up

While it is true that frequent change in technological knowledge and quick obsolescence of old knowledge provide good opportunity for the late-comers, it is important to note that such catching-up leapfrogging happen not only based on indigenous knowledge but also more critically dependent upon foreign knowledge. One of the most important characteristics of the latecomer firms is being resource-poor (Mathews, 2002). Among the diverse resources constituting a firm, knowledge is critical in the context of technological catch-up which is basically an act of reducing the knowledge gap with the advanced countries. Then, the possibility of access to existing knowledge base determines largely the possibility of catch-up because the late-comer firms do not command sufficient capability to generate knowledge by themselves. As asserted by Hu and Jaffe (2003), while it is natural for advanced economies to create most of this knowledge stock, non-advanced economies try to tap into this stock, constrained by the limited channels of knowledge diffusion and their abilities to absorb and adapt new knowledge. In this way, the knowledge from advanced countries has the function of facilitating technological development in catching-up economies. Hence, the extent of spillover from advanced countries to catching-up economies in each sector has importance for catch-up.

Quantitative study using the patent data has proven, comparing the level of technological capability of the advanced and catching-up economies, that catching-up countries tend to achieve high levels in the sectors with easier access to knowledge (Park and Lee, 2004). The reason for the importance of foreign knowledge comes from the fact that in most cases, the core competences of catching-up firms is not much product innovation using world first knowledge but combination of production engineering, project execution capabilities and detailed designing (Amsden and Chu, 2003). Case studies in Lee and Lim (2001), Lee, Lim and Song (2005), and Mu and Lee (2005) all confirms the importance of access to the external knowledge base, namely the issue of technology transfer although specific channels were different in different industries. The alternative channels include: informal learning, licensing, FDI, strategic alliance, co-development, and so on.

6.1. Licensing vs. FDI

One issue in technology transfer is the relative superiority of licensing vs. FDI. In the early days of industrialization, on-site instructions from the buyers in OEM export contract were important in Korea. Other than this, the main form of technology transfer was imports of licensed technology in the 1970s and the 1980s (OECD, 1996, p. 91, 149, 184). Up to a certain point in their development, consumer electronics and PCs were able to catching-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. Thus one might say that more close and long term collaboration or integration with the foreign firms via FDI or subcontracting might be better in stabilizing the source and flow of new technology.

However, when licensing from big production companies is not available, alternative sources can be found in small technology or R&D companies. Also, as the examples of Hyundai Motors and Samsung Semi-conductors show, small R&D specialist companies in the advanced can be a source for new knowledge in the form of co-development contract. When big production companies refuse to transfer technologies the latecomer firms were able to get help from the specialized R&D or venture firms. 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. Also, for Chinese companies, smaller sized Korean companies have been the sources of new technology, notably in IT sectors (Lee and Kim, 2004).

Furthermore, some doubt can be expressed against FDI as a channel of learning. 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 foreign shareholders, including Mitsubishi, and took the sole responsibility of key

R&D projects such as engine development. With help from the specialized R&D companies like Ricardo, Hyundai's technological capability grew in a steady manner. In contrast, although Daewoo shared its ownership and 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 achievements from its own R&D effort.

The Chinese case of digital telephone switch development suggests that FDI or JV can rather be a source of new knowledge to the local indigenous firms and R&D units trying absorb new knowledge. However, it should be noted that successful indigenous R&D did occur not at the JV itself but other local firms and people who purposely absorbed knowledge from the JVs through mobility of engineers and scientists, on-site observation and learning, and even participation at the adaptation process of foreign-made products in China (Mu and Lee, 2005).

These experiences in Korea and China 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, having such JV in locality give the neighboring late-comer firms some window of learning and imitations as the experience of Taiwan suggests. In the early days of industrial development, foreign firm dominated the industry in China and provided learning opportunity for Taiwanese engineers who later emerged as the founder of local companies (Amsden and Chu, 2003).

6.2. In-House R&D and Pubic-private R&D consortium

Along the path of development, the late-comer firms soon reach stage that in-house R&D is the main form of technology acquisition. In the case of Korea, the motivations for transition from licensed technology to in-house R&D were three folds (OECD, 1996 pp. 91-92). First, foreign firms became more reluctant to provide core technology. Second, after the early 1980s, Korea lost its comparative advantages associated with cheap and skilled labor, and, as a results, Korean firms keenly recognized the need to develop their own technological capabilities. Third, government policy also changed to support private R&D. The share of R&D in sales in private firms was around 0.5% in 1982, and it soon reached 1% by the mid 1980s and surpassed 2% by the early 1990s (OECD, figure 8.1). While incomparable to the public R&D by the 1970s, the size of private R&D soon matched the size of public R&D by the mid 1980s and became to account for more than 80% of total R&D in Korea since the early 1990s.

However, for certain big or risky R&D project and for the project requiring high level of design technology, diverse forms of R&D consortium can be an effective vehicle for technological catch-up. The long list of success with the public-private R&D consortium, from TDX, D-RAM, CDMA and finally to digital TV in Korea, confirms the positive role of the government and the government research institutes in technological catch-up by the late-comer firms. In these cases, the consortium led by the GRIs developed new products and provided design technology to the participating firms for production (OECD, p. 109).

In China, a successful example is the tripartite R&D consortium which was responsible for the indigenous development of digital switches (HJD-04) (Mu and Lee 2005). The three organizations are the Center for Information Technology (CIT) under the Zhengzhou Institute of Information Engineering of the People's Liberation Army, the Posts and Telecommunications Industrial Corporation (PTIC), and the Luoyang Telephone Equipment Factory (LTEF) of MPT. The CIT was the research arm of the Army and served as the initiator of the project; the PTIC was originally the procurement unit of the MPT and played the role of the general project manager and financial sponsor,; and the LTEF was formally a producer of crossbar switches and later emerged as the initial producer of the HJD-04.

The case of consortium to develop digital TV in Korea show that collaboration and knowledge sharing among the private firms has certain limits within the framework of consortium because of intrinsic rivalry among them (Lee, Lim and Song, 2005). However, these participating firms all acknowledged the important function of the government in providing the legitimacy to the big projects that are often difficult to be supported for long time by private firms. The consortium also served as a field to pool together the domestic resources from various sources, especially resources in the universities that is often a reservoir of new scientific findings. Contribution of the GRI's is also critical in conducting the role of "technology watch" to interpret and monitor the state-of-the art trend of R&D activities in foreign countries. It was the ETRI who identified the small firm like Qualcomm as the R&D partner and carried out R&D activities.

6.3. Role of the GRIs in Knowledge Diffusion

The difference between Korea and Taiwan is also remarkable in terms of intra-national knowledge diffusion or localization of knowledge creation. Adopting a similar approach as Jaffe, et al (1993), Lee and Yoon (2004) test whether or not knowledge diffusion among the firms in Taiwan was stronger than among the firms in Korea, and examine the role of government research institutes (GRIs) in the intra-national knowledge diffusion.

In the semi-conductor industry, in the case of Korea, most of DRAM (dynamic random access memory chips) patent were obtained by Chaebol firms such as Samsung, Hyundai, and LG from the early period of their entry into the industry. By contrast, most of the DRAM patents obtained by Taiwan during its early stage after the entry were those by the ITRI, a national research institute. Such difference is confirmed by Table 2 and Table 3. That is, in the case of Korea, the first patent grant was not by the ETRI, a Korea's national research institute, and the number of patents grants by ETRI was less than the number of patents of private firms. In contrast, in the case of Taiwan, the ratio of patent grants by the ITRI has featured highly until 1994, but recently decreased with increasing tendency of patent grants by private firms. Such a trend indicates that the government has been instrumental in R&D at the initial stages, but now increasing shares are by private companies.

The importance of the ITRI in R&D in Taiwan's DRAM industry is also evident when we examine patents citation. Table 3 presents Taiwanese patents cited by Taiwanese measured by the number of citation counts per patent. The high incidence of citation counts per patent held by the ITRI in the initial stage implies that knowledge diffusion occurred much from the ITRI to other Taiwanese firms. Although the number of citation counts per patent by the ITRI did not decline until recently, the increasing number of citation counts per patent of other private firms indicates the somewhat declining importance of the ITRI.

Table 2 : Number of DRAM Patents by Taiwanese Firms

	ITRI	TSMC	United	Vanguard	Mosel
1990	1	0	0	0	0
1991	0	0	0	0	0
1992	3	0	0	0	0
1993	5	0	0	0	0
1994	8	1	2	0	0
1995	9	1	16	0	0
1996	9	1	13	13	0
1997	7	10	5	19	3
1998	3	18	26	46	5
1999	0	14	49	39	7

Source: Lee and Yoon (2004).

Table 3 : Taiwanese Patents Cited by Taiwanese Firms

	TSMC	United	ITRI	Vanguard	Mosel
1995	2	0	21	0	0
1996	3	3	20	0	0
1997	1	9	16	6	0
1998	9	18	28	22	0
1999	17	17	25	45	3

Note: measured by the number of citation counts per patent.
Source: Lee and Yoon (2004).

While there are few patents by the ETRI in semi-conductor this does not necessarily mean that the role of the government or the GRI (government research institute) was minimal in Korea. As explained in Lee and Yoon (2004) and Bae (1997), KIET, the former entity of ETRI, has contributed significantly in the technological development process for semiconductor until the early 1980s. In addition to the direct role in research and development, KIET has played other important roles including training of engineers and organizing co-research activities. The ETRI, the latter entity of KIET, similarly led private-public co-development systems in 1986 as the core of a semiconductor research association formed by Samsung, Goldstar, Hyundai and others, under which the 4MB DRAM was developed. The role of the ETRI in the early stages of development has been significant in the sense that the technological innovation of Korean firms accelerated tremendously after the production of 4MB DRAM. Since the late-1980s, the role of the ETRI in developing the DRAM industry has almost disappeared because its technological capability over private firms up until the mid-1980s became no longer superior after the late-1980s (Hong, 1993).

This reflects that the contribution of the ETRI was very large in the imitation stage, and mainly in basic research, and the during the later or development stages, then the initiatives have moved to private firms. In contrast, in the case of Taiwan, the ITRI in Taiwan played a very significant role by not only accumulating patents from the very early stages but also transferring them to spin-off firms, such as TSMC and United. The reason for the difference in the government's role in the DRAM industries of Korea and Taiwan is possibly due to differences in the corporate organization. As Lee and Lim (2001) pointed out regarding the technological regime of the semiconductor (memory chip) industry, fluidity of technological trajectory is relatively low and innovations are more frequent. Thus, R&D success in this kind of industry requires concentrated R&D and a large scale of R&D budget in a very short period. Such technological environment is advantageous to Korea which is centered on the Chaebol firms. In contrast, the Taiwanese small- and medium-sized firms should have found it difficult to independently carry out risky investments over the short time period. Consequently, the Korean government had played only a complimenting role, whereas the Taiwanese government had played a critical role particularly in mitigating risks faced by firms in the early stage of R&D.

6.4. Co-Development and Overseas R&D Outpost and M&A: Absorption Capacity to Complementary Asset

While access to foreign knowledge should be arranged in the forms of licensing, FDI, or scouting, development or commercialization effort is still required in which the absorption capacity of the recipient firms or countries is critical. Even in the case of knowledge and technology which reside in the public institutions and thus allow relatively easier access than otherwise, this does not mean that they are in a state ready-to-be-used in factories (Perez and Soete, 1988). 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 from Qualcomm. It is the absorption capacity of the late-comer firms that determines the detailed conditions of the technology transfer contract and nature of the access.

Another element for success is to have complementary asset or capability, which is similar but also different from, the concept of absorption capacity. I would say that while absorption capacity was more important when the stage of growth of technological capability of catching-up firms are relatively low, as their capacity grow high enough to have some horizontal collaboration, having complementary asset become more important.

In the case of CDMA mobile phone development, the collaboration between the Qualcomm and the Korean consortium was possible because each side needed something from the other side (Lee et al, 2005): the Korean needed the core source technology and basic research capability from Qualcomm, while Qualcomm needed R&D money, commercialization capability, and engineering skills backed up by hardware facility. As the case of digital TV shows, despite the lack of sufficient capability and core knowledge base, the Korean firms had some complementary asset. Korean companies had some engineering capability in digital TV in that roughly 60% of the production process of digital TV sets is as same as that of analogue TV. R&D units in the advanced countries have need support from a team with engineering and production experiences as well as hardware. A collaborative project for digital TV between GI and Samsung was realized because GI needed a partner in developing prototype digital TV, specifically hardware-level assistance in GI's R&D activities. Horizontal collaboration with forerunning firms is possible only when the late-comer firms have something to give in return. While absorption capacity was emphasized in the old story of technology transfer via license or FDI, now complementary assets, which have been created with speedy R&D activities and investment in production, seems to be important in these new ways of accessing knowledge.

6.5. Sequential Changes in Access Modes to Knowledge and Strategies

Above discussion suggest the following pattern in the evolution of the channels of access to foreign knowledge. First in the earliest stage, the primary channel of learning is technical guidance from foreign OEM buyers or learning by working in FDI firms. Key technology is embodied in imported machinery and equipments. It is basically learning by doing with no capacity or even intention for planned technological development. In the late 1960s and 1970s in Taiwan, engineer learned skill by working in American firm or in joint venture with Japan (Amsden and Chu, 2003).

In the next stage when the late-comer firms recognize the need for more systemic learning and planned technological development, such firms tend to resort to technological licensing and be actively seeking learning or transfer from any FID partners. Licensing had been the main form of acquisition of foreign technology in Korea during the 1970s and the 1980s. In Taiwan, in the 1980s in the monitory industry which emerged after the television industry of the 1970s, the main channels were licensing or joint ventures (Amsden and Chu, 2003). In this stage, critical factor for effective learning would be absorption capacity of the elate comer firms which also depend on education system and other elements of the national innovation system of the country. In some case, the distinction between the first two stages might not be that clear.

In the next stage, the late-comer firms establish a certain degree of in-house R&D capacity with clear idea of what should be done how with how much resources to be allocated. With licensing or learning from foreign partners reveal its limits, the late-comer firms now should rely on public-private R&D consortium, the GRIs, research of the existing literature, overseas R&D outpost, co-development contract with foreign R&D or technology specialist firms and/or international M&A. In the 1990s, the main channel of access was government lab in the case of notebook industry in Taiwan (Amsden and Chu, 2003). It was also from the early 1990s that a small number of Korean firms have begun to establish overseas R&D posts, mainly in order to obtain easy and faster access to foreign technology that are hard to acquire through imports of licenses technology. These overseas posts also served as a window on recent trends in technological development (OECD, p. 97)

The final stage would be horizontal collaboration or alliance based on complementary assets. Some Korean firms like Samsung have reached this stage, and is now engaged with Intel, Sony, Toshiba, and MS in diverse modes of alliances.

Also, the fact that in final stage of catch-up, the nationally owned firms has eventually emerged as the leader of the industry even in Taiwan, suggest the important of ownership of the firms in technological catch-up. The FDI firms cannot be relied upon the technological development of the late-comer countries, although they can serve as initial learning place. As Amsden and Chu put it (2003, p. 3), technologic catch-up requires using assets related to project execution, product engineering, and a form of R&D that straddles between applied research and exploratory development, and if such assets are to be accumulated at all, the responsible party tend to be a nationally owned organizations. By its nature, the FDI firms have no reason or incentives to develop its own development capabilities which reside in the mother companies abroad. In sum, ownership matter at least in R&D.

This observation on the role of the FDI or international subcontracting does not mean that the late-come countries should not invite foreign firms. Many Korean chaebols once had or even currently have a FDI or OEM relations with foreign MNCs which served as a learning place. The Taiwan path from OEM to OBM via ODM might be a more standard path. Also, 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. Several Korean firms have now reached this stage, and the old standing-alone strategy might not be effective anymore. However, the alliance strategy is possible and can work only after the late-comer firms have become to commands higher technological capability, which affects their bargaining positions. In other words, the existing technological capability and base of local firms matters since they determine the concrete terms of the technology-related contract between the local and foreign firms.

There is also need to look at the issue beyond the relative roles of private in-house R&D and public-private consortium, and to take the national innovation system approach that requires coordination among the firms, government agencies, and academia. To generate some jump of acquiring design and product development capability, 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, turning new ideas into actual business. In this regard, one great achievement in the late 1990s by the Korean government was the establishment of the

KOSDAQ stock market, like 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 were 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 firms are flexible.

A related area for attention is the facilitation of industry-university collaboration not only in the traditional forms of supplying human resources but also conducting contract R&D for industry and even establishing companies directly using the resources of universities. The new phenomenon called "knowledge industrialization" has become increasingly important as more and more industries are becoming "science-based" rather than on-site experience.

7. Two or Three Models for Catch-up

Above discussion suggest that there seems to be two different pathways to catch-up, the one taken by Taiwan and the other by Korea, although some other variations are also possible.[7]

7.1. The Korean Model

The Korean path is led by a few large firms who are nationally-owned and independent from the MNCs in terms of financing, production, and marketing (brand). During the very early stage (1970s) along this path, these private firms were helped by the GRIs in getting their R&D results freely or cheaply, but soon they consolidated their own in-house R&D capacity and emerged as the technology leader although they sometimes needed the government help in the form of R&D consortium in large scale and high risk projects. These private empire-building firms were independent and not integrated with the MNCs or the GPN in the sense that their equity shares are not owned by the MNCs and they are not subcontractors. However, they relied on other diverse firms in the advanced countries, such as R&D firms, small technology firms and other MNCs, as the sources for new knowledge in the form of embodied technology importations, licensing, co-development, and horizontal collaborations. On the other hands, these chaebols are also independent each other, without much collaboration or exchange of knowledge among them. In contrast, each chaebols, behaving like a flagship firm, have brought up and maintained

7) For example, Mathews (2001) discusses Singapore as the third model.

its own network with subcontracting or collaborating firms.

7.2. The Taiwan Model

The Taiwan path was initially led by a large number of the SMEs who are more or less integrated with the MNCs in terms of financing, production, and marketing (brand). During the very early stage along this path, these private firms were starting as OEM contractor for the MNCs and integrated with the GPN which helped them accessing new knowledge and upgrading to higher tier in the GPN (Ernst, 2002 ; Ernst and Kim, 2002). Some of them become highly successful so as to rise as large scale OBM via ODM but they, even the big firms like Acers, still do lots of subcontracting with the MNCs. The R&D activities by these firms were more active in such sectors allowing high appropriability and less persistence by the incumbent firms from the advanced countries. On the other hand, in such sectors requiring bigger capital and risk, they were helped by the GRIs as the sources of new knowledge and/or new spinoff firms from the government sector. On the other hands, these Taiwan firms are in intense collaboration or exchange of knowledge among them. The network in Taiwan, as typically observed in electronics was a geographical agglomeration consisting of firm conducting transactions at arm's length, involving no intra-local subcontracting (Amsden and Chu, 2003). The benefits of its density to local assemblers were low transaction costs and high global visibility for new orders.

7.3. China, the Third Model?

Finally, it is interesting to which pattern will prevail in another rapidly catching-up country of China. Roughly speaking, China might be a third model mixing both Korean and Taiwanese models in it. China has developed a large segment of industries dominated by FDI from neighboring economies of Asia, from Japan, Taiwan, Hong Kong, Korea, and Singapore. They seem to be going along the path of gradual catch-up of OEM, ODM and OBM. On the other hands, China boast of a relatively large number of big firms such as Renovo (which acquired the PC business sof IBM), Hair (largest refrigerator maker in the world), Changhong, TCL, Kongka, Huawei and so on. China already has 11 fortune global 500 firms, as many as Korea. They are brand leaders in China but final assembles and lacks strong design capability. They might be going along the path of Korean chaebols, and some of them are achieving similar leapfrogging.

8. Summary and Concluding Remarks

This paper has discussed several issues regarding the barriers and opportunities for technological catch-up by the late-comer countries and firms. As one of the barriers to technological catch-up, the paper emphasizes the uncertainty involved with the third stage of learning how to design. The barriers arise because as the forerunner firms refuse to sell or give license to successful catching-up firms who thus have to design the product by themselves. But, we note that this crisis is also a window of opportunity for leapfrogging type catch-up ("stage-skipping" or "path-creating" catching-up), when the late-comer succeeds in designing their own products. The paper observes that if the crisis of design technology is a push factor for leapfrogging or upgrading, arrival of new techno-economic paradigm can serve as a pull factor for leapfrogging, serving as a winder of opportunity.

While the existing literate has discussed the facilitating factors for leapfrogging in terms of the three aspects of production capacity, human resources, and locational advantages, this study has rather emphasized the two risks with leapfrogging, namely the risk of choosing right technology or standards and the risk of creating initial markets, and how to overcome these risks. Then, the paper discusses and differentiates diverse forms of knowledge accesses, and suggests the following pattern in the evolution of the channels of access to foreign knowledge. First in the earliest stage, the primary channel of learning is technical guidance from foreign OEM buyers or learning by working in FDI firms. Key technology is embodied in imported machinery and equipments. In the next stage such firms tend to resort to technological licensing and be actively seeking learning or transfer from any FDI partners. In the third stage, the late-comer firms establish a certain degree of in-house R&D capacity, which is to be supplemented by public-private R&D consortium, GRIs, overseas R&D outposts, co-development contract with foreign R&D or technology specialist firms and/or international M&A. The final stage would be horizontal collaboration or alliance based on complementary assets.

Then, the paper takes up the issue of whether there can be a single common or several models for catch-up. The possibility of one single model is discussed in terms of the given same feature of catch-up itself which is basically is to source their high-tech inputs from overseas and thereby create their scarcities in other inputs, design or functions when a "new" mature products is still hot (Amsden and Chu, 2003, p. 163, 167). While the private R&D of the first mover include basic or some applied research, that of the late-comer as the fast second mover is closely coupled with production and detailed design. Thus, a common element of catching-up is to enter new markets segments quickly, to manufacture with high levels of engineering excellence, and to be first-to-market by means of the best integrative designs. This observation is supported by the fact that Korea and Taiwan has achieved higher levels of technological capabilities in such sectors as featured by short cycle time of technology whereas the advanced countries do significantly better in those sectors with longer cycle time (Park and Lee, 2004). The fact that when knowledge become quickly obsolete, catch-up is more likely occur is consistent with the insights of leapfrogging which states the paradigm changes serve as a window of opportunity of late-comers.

The possibility of two models for catch-up is also discussed in terms of the key difference between Korean and Taiwan, especially in the position toward the source of foreign knowledge and the paths taken toward the final goal of OBM. Taiwan followed the sequential steps of OEM, ODM and OBN, in collaboration or integration with the MNCs, and none of the firm is yet to be listed in Fortune global 500. Korean chaebols jumped from OEM directly to OBM even without consolidating design technology, independently from the foreign firms, and Korea has listed more than 10 in Fortune global 500 as of 2000. In Taiwan case, disadvantage of being smallness and need for technological breakthrough had to be overcome by deliberate government intervention in R&D which lead to spin-offs and technology transfer to private firms. In Korean case, for large and risky project, public-private R&D consortium played an important role as seen the list of such cases of TDX in 1970s, CDMA in the 1980s, and digital TV in the 1990s.[8)]

Based on the discussion of many cases, the paper agues for the importance of the government involvement in the late-comer's technological catch-up, although the exact forms of intervention might change over industry and stages. Also argued is the importance of ownership of the firms as FDI cannot be relied upon the technological development of the late-comer countries although they can serve as initial learning place. The role of the government and/or government research institutions are also discussed as one way to deal with the two kinds of risk with leapfrogging as it can plays the role of facilitating the adoption of specific standards and thereby influencing the formation of markets at the right times.

8) TDX development case was one of the successful cases of Korean technology catch up. This TDX system was so successful it has been exported to South Asia South America and Eastern Europe. The TDX development project was by collaboration between the ETRI (a GRI) and other electronics firms. In the case of CDMA, ETRI did have a partial leading role in developing integrated communication system.

References

Albert, M. (1998), *The New Innovators: Global Patenting Trends in Five Sectors*, U.S. Department of Commerce Office of Technology Policy.

Acemoglu, D., Johnson, S. and Robinson, J. (2001), "Colonial Origins of Comparative Development", *American Economic Review*, Vol. 91, pp. 1369-1401.

Amsden, A. (1989), *Asia's Next Giant: South Korea and Late Industrialization*, Oxford: Oxford Univ. Press.

Amsden, A. and Chu, W. (2003), *Beyond Late Development*, MIT Press.

Bae, Yong-ho (1997), "Development of Technological Capability in the Semiconductor Industry", in Lee, K. et al. (eds.), *Technological Capability and Competitiveness of Korean Industries*, pp. 169-214, Seoul: Kyung-moon-sa (in Korean).

Breschi, S., Malerba, F. and Orsenigo, L. (2000), "Technological Regimes and Schumpeterian Patterns of Innovation", *Economic Journal*, Vol. 110, pp. 388-410.

Cargill, C. F. (1989), *Information Technology Standardisation: Theory, Process and Organisations*, Bedford MA: Digital Press.

Chang, Ha-Joon (1994), *The Political Economy of Industrial Policy*, New York: St. Martin Press.

Christensen, C. M. (1997), *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press.

Clark, K. B. (1985), "The Interaction of Design Hierarchies and Market Concepts in Technological Evolution", *Research Policy*, Vol. 14, pp. 235-251.

Dahlman, C., Westphal, L. E. and Kim, L. (1985), "Reflections on Acquisition of Technological Capability", in Rosenberg, N. and C. Frischtak (eds.), *International Technology Transfer: Concepts, Measures and Comparisions*, New York: Pagamon.

Dosi, G. (1982), "Technological Paradigm and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change", *Research Policy,* Vol. 2, No. 3, pp. 147-62.

Ernst, D. (2000a), "Catching-up and Post-Crisis Industrial Upgrading: Searching for New Sources of Growth in Korea's Electronics Industry", in Deyo, F., R. Doner, and E. Hershberg (eds.), *Economic Governance and Flexible Production in East Asia,* Rowman & Littlefield Publishers.

Ernst, D. (2000b), "Inter-orgnizational Knowledge Outsourcing: What Permits Small Taiwanese Firms to Compete in the Computer Industry", *Asia-Pacific Journal of Management*, Vol. 17, No, 2, 223-255.

Ernst, D. and Kim, L. (2002), Global Production Networks, Knowledge Diffusion, and Local Capability Formation, *Research Policy,* Vol. 31.

Ernst, D. (2002), "Global Production Networks and the Changing Geography of Innovation Systems; Implications for Developing Countries", *Economics of Innovation and New technology*, Vol. 11, No. 6.

Freeman, C. and Soete, L. (1997), "Development and the Diffusion of Technology", in Freeman, C. and Soete, L. (eds.), *The Economics of Industrial Innovation*, London: Pinter Publishers,

Gerschenkron, A. (1962), *Economic Backwardness in Historical Perspective*, Cambridge, Mass.: Harvard University Press.

Gerschenkron, A. (1963), "The Early Phases of Industrialization in Russia: Afterthoughts and Counterthoughts", in W. Rostow (ed.), *The Economics of Take-off into Sustained Growth*, London: Macmillan.

Guillen, M. (2001), *The Limits of Convergence: Globalization and Organizational Change in Argentina, South Korea, and Spain*, Princeton University Press.

Henderson, R. M. and Clark, K. B. (1990), "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established firms", *Administrative Science Quarterly*, Vol. 35, pp. 9-30.

Hong, Sung-gul (1993), "Developmental Corporatism: The State-Industry Relationship in the Development of the Korean Semiconductor Industry", *Korean Public Administration Review*, Vol. 27, No.3 (in Korean).

Hu, Albert G. Z. and Jaffe, A. B. (2003), "Patent Citations and International Knowledge Flow: the Cases of Korea and Taiwan", *International Journal of Industrial Organization,* Vol. 21, No. 6, pp. 849-880, June.
Jaffe, A., Manuel, T., and Rebecca, H. (1993), "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations", *Quarterly Journal of economics,* Vol. 108.
Kim, Kyun, (1994), "The Mechanism of the Growth of the Korean Automobile Industry from the Technological Point of View: The Case of Hyundai", Sa-hoi Kyung-Jai Pyung-Ron, Vol. 7 (in Korean).
Kim, Linsu (1998), "Crisis Construction and Organizational Learning: Capability Building in Catching-up at Hyundai Motor", *Organization Science*, Vol. 9.
Kim, Linsu (1997a), *Imitation to Innovation: The Dynamics of Korea's Technological Learning*, Boston: Harvard Business School Press.
Kim, Linsu (1997b), "The Dynamics of Samsung's Technological Learning in Semi-Conductors", *California Management Review,* Vol. 39, No. 3.
Kim, Linsu (1980), "Stages of Development of Industrial Technology in a Developing Country: A Model", *Research Policy,* Vol. 9, pp. 254-277.
Klepper, S. (1996), "Entry, Exit, Growth, and Innovation over the Product Life Cycle", *American Economic Review*, Vol. 86, No. 3.
Lee, Keun, and Chaisung Lim (2001), "Technological Regimes, Catching-up and Leapfrogging: the Findings from the Korean Industries", *Research Policy*, pp. 459-483.
Lee, Keun, Chaisung Lim, and Wichin Song (2005), "Digital Technology as a Window of Opportunity and Technological Leapfrogging: Catch-up in Digital TV by the Korean Firms", *International Journal of Technology Management,* Vol. 29, No. 1/2, pp. 40-64.
Lee, Keun, and Yoon, M. (2004), "Inter-national and Intra-national Knowledge Diffusion and Technological Catch-up", Paper presented at the international conference on economic cooperation and development in northeast Asia, organized by the Korean Association for Development Economics.
Lee, Keun, and Mihnsoo Kim (2004), "The Rise of China and the Korean Firms Seeking New Divisions of Labor", Paper presented at the international conference on the China and East Asia, organized by the KIEP.
Malerba, F. and Luigi, O. (1996), "Schumpeterian Patterns of Innovation Are Technology-specific", *Research Policy*, Vol. 25, Issue 3, pp. 451-478.
Mathews, J. A. (2001), "National System of Economic Learning: The Case of Technology Diffusion Management in East Asia", *International Journal of Technology Management*, Vol. 22, No. 5-6, pp. 455-479.
Mathews, J. A. (2002a), "Competitive Advantages of the Late-comer Firms: A Resources Based Account of Industrial Catch-up Strategies", *Asia Pacific Journal of Management*, Vol. 19, No. 4, pp. 467-488.
Mathews, J. A. (2002b), "The Origins and Dynamics of Taiwan' s R&D Consortia", *Research Policy*, Vol. 31, pp. 633-651.
Mathews, J. A. (2003), "Competitive Dynamics and Economic Learning: An Extended Resource-based View", *Industrial and Corporate Change*, Vol. 12, No. 1, pp. 115-145.
Mu, Qing, and Keun Lee (2005), "Knowledge Diffusion, Market Segmentation and Technological Catch-up: The Case of Telecommunication Industry in China", *Research Policy* (in print).
OECD (1996), *Reviews of National Science and Technology Policy: Republic of Korea*, Paris: OECD.
OECD (1992), *Technology and Economy: the Key Relationships*, Paris: OECD.
Park, K., and Keun Lee (2004), "Linking the Technological Regime to Technological Catch-up: An Empirical Analysis Using the US Patent Data" paper presented at the Globelics conference held in Beijing, China.
Penrose, E. (1959), *The Theory of the Growth of the Firm*, New York: John Wiley
Perez, C. and Soete, L. (1988), *Catching up in Technology: Entry Barriers and Windows of Opportunity in Technical Change and Economic Theory*, New York: Pinter Publishers.
Perez, C. (1988), "New Technologies and Development", in Freeman, C., and B. Lundvall (eds.), *Small Countries Facing the Technological Revolution*, London and New York: Pinter Publishers.

Rodrik, D., Subramanian, L. and Trebbi, F. (2004), "Institutions Rule: The Primacy of Institutions over Geography and Integration in Economic Development", *Journal of Economic Growth*, Vol. 9, No. 2, pp. 131-165.

Saxenian, A. and Hsu, J. Y. (2001), "The Silicon Valley-Hsinchu Connection: Technical Communities and Industrial Upgrading", *Industrial and Corporate Change,* Vol. 10, No. 4, pp. 893-920.

Shapiro, C. and Varian, H. R. (1998), *Information Rules: A Strategic Guide to the Network Economy*, Boston: Harvard Business School Press.

Utterback, J. M. and Abernathy, W. J. (1975), "A Dynamic Model of Process and Product Inovation", *Omega*, Vol.3, No. 6, pp. 640-656.

Vernon, R. (1966), "International Investment and International Trade in the Product Cycle", *Quarterly Journal of Economics,* Vol. 80, pp. 190-207.

World Bank (1993), *The East Asian Miracle: Economic Growth and Public Policy*, New York: Oxford Univ. Press.

Wallenstein, G. (1990), *Setting Global Telecommunications Standards: The Stakes, the Players and the Process*, Dedham: Artech House, pp. 19-20.