Making a Technological Catch-up: Barriers and Opportunities

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Abstract

This paper provides a synthetic account of technological catch-up by incorporating the stylized facts from empirical and theoretical researches on the catch-up.

This paper starts by combining the three patterns of catch-up with the sequential pattern of knowledge creation during the stages of technological catch-up, based upon the experience of the Korean and Taiwanese firms. The four stages are identified, starting with the first stage, mainly involving the latecomers’ learning skills by socialization of foreigner-held skills, and moving into the second stage of acquiring process technology by internalization of product design; In the third stage, they become able to design imitatively the existing products by externalization of implicit design technology held by specialized R&D firms and personnel abroad, and finally become able to conduct real innovation by creating a new product concept through a combination of domestic and foreign explicit knowledge. It is argued that the first and second stages largely correspond to the duplicative imitation and path-following catch-up, and that the third stage corresponds to creative imitation and stage-skipping catch-up and the final stage, to real innovation and path-creating or leading catch-up.

We note that at every stage, access to foreign knowledge base, in whatever form, is very critical, and thus, Section 3 discusses this issue of access to foreign knowledge base in detail. The paper discusses and differentiates diverse forms of knowledge access, such as importation of equipment, licensing, FDI, co-development, overseas R&D outposts, scouting of key researchers, and international M&A. The paper emphasizes, as one of the barriers to technological catch-up, the uncertainty involved with the third stage, which is something similar to a "crisis" or a critical stage in that the late-comer firms face difficulty as they see many forerunner firms now refusing to sell or give them license and they have to design the product themselves. We note, however, that this crisis is also a window of opportunity for a leapfrogging-type catch-up ("stage-skipping" or "path-creating" catch-up), when the latecomer succeeds in designing its own products. While the existing literature has discussed the facilitating factors for leapfrogging, this paper emphasizes the two, namely, the risk of choosing the right technology or standards and the risk of creating initial markets.

The paper also takes up the issue of whether there can be a common single or several models of catch-up. It finds that a common element of catching-up is to enter new market segments quickly, to manufacture with high levels of engineering excellence, and to be first-to-market by means of the best integrative designs, while the possibility of two models for catch-up is also discussed in terms of the key difference between Korea 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, while Korean chaebols jumped from OEM directly to OBM even without consolidating design technology, independently from the foreign firms.

Based on the discussion of many cases, the paper agues for the importance of the government intervention in the latecomer’s technological catch-up, although the exact forms of intervention might change across industry and stages. Also argued is the importance of ownership of the firms as FDIs cannot be relied upon for the technological development of the latecomer countries although they can serve as initial learning place.

Comment [n.a.1]: Verify if this is correctly stated, or if this should be "involving the merging of latecomers' learning skills with those of foreign skills."

Comment [n.a.2]: Indicate what "they" refers to.

Comment [n.a.3]: Provide full form of this acronym.

Comment [n.a.4]: Provide full form.

Comment [n.a.5]: Provide the full forms of these acronyms.

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 world. Despite huge amounts of development aid and accompanying policy changes, poverty and the gap between the rich and poor countries still prevail. The argument has been made that even good policy prescriptions fail because of poor institutional conditions, such as insecure property rights 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).

There is no doubt that institutions of a given society affect the path of its economic development by structuring political, economic, and social interactions among its members (Greif 1994; North 1981; Williamson 1985). As such, institutions can either promote economic development or retard it. As noted by North (1998), societies that are stuck in an "institutional matrix" that does not evolve into the impersonal exchange will fail to achieve economic growth, as they are unable to capture productivity gains that come from the specialization and division of labor. Thus one of the critical things that the developing countries must undertake to bring about economic development is to introduce "correct" institutions in the three areas of market regulating, market stabilizing, and market legitimizing (Rodrik, etc 2004). Then, there is the role of good "policies" to introduce good institutions.

Noticeably missing in the debate on the determinant of economic development is the role of technology. However, 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 are not sufficient to trigger sustained growth.[1] 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) who 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 technology only after it become mature enough to have the capital goods suitable for efficient production. However, 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; Lall 1980; 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).[2] However, the speed of progress on the track has been uneven, with some catching-up rapidly and others lagging behind.

An institution-oriented account of such divergence would be the national innovation system approache, which attributes the divergence to the difference in the NIS of each country

[1]. Specifically in recognition of this, the World Bank recently held a conference in February 2005 on the "how to" of technological change and adaptation for faster growth.
[2] . An exception would be Dahlman, Ross-Larson, and Westphal (1987), who recognized the idiosyncrasies of technology transferred and adapted locally.

(Lundvall 1992; Nelson 1993; Edquist 1997). The NIS is a web of institutions affecting innovation capability of a nation, such as in-house R&D capability of the firms, industry-university relations, financial systems supporting innovative firms, education systems, quality of government services, and so on. However, the NIS approach is not incompatible with the policy-oriented view since good policies could affect or improve the NIS of a country.

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) identified the three different patterns of catch-up: a path-following catch-up, which means the latecomer firms follow the same path taken by the forerunners; a stage-skipping catch-up, which means that the latecomer firms follow the path but skip some stage, and thus save time; and a path-creating catch-up, which means that the latecomer firms explore their own path of technological development. Then, some countries make quick progress and save time because they achieve some leapfrogging by taking advantage of new techno-economic paradigm or skipping some stages or even creating 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 latecomers like NIEs. The idea of leapfrogging is that some latecomers may be able to leapfrog older vintages of technology, bypass heavy investments in previous technology system and catch-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).

One can also pay attention to the sectoral difference among the countries in making success or failures. This idea is consistent with view focusing on sectoral innovation system (Marlerba 2004) or the concept of technological regimes. The concept of the technological regime was first introduced by Nelson and Winter (1982) as a theoretical framework to interpret the variety of innovative processes observed across industrial sectors, and they have distinguished the science-based and cumulative regimes. The notion of the technological regime defines the nature of technology according to a knowledge-based theory of production, and it defines the particular knowledge environment where firm problem-solving activities take place (Winter 1984). Breschi *et al.* (2000) try to define technological regimes as particular combinations of key dimensions. They posit four fundamental factors – technological opportunity, appropriability of innovations, cumulativeness of technological advances, and properties of the knowledge base. This neo-Schumpeterian notion of technological regime has been used to explain the specific way in which innovative activities of a technological sector are organized (Breschi *et al.,* 2000; Malerba, 2002; Malerba and Orsenigo, 1996, Malerba *et al*., 1997). While most studies focused on the situation in developed economies, it was only in Lee and Lim (2001) and Lee, Lim and Song (2004) where the concept of technological regimes was linked to technological catch-up by the latecomer firms (Mathews 2002) from developing countries in their case studies of seven industries in Korea.

Comment [n.a.6]: Verify if this is the intended phrase, or if it should be "problem-solving activities in firms" instead.

Another stream of research focuses on the 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). In this tradition, a conceptual framework is grounded by a pioneering work of Nonaka and Takeuchi (1995), Nonaka (1994), and Nonaka (1988). In this, a key concept is the four modes of knowledge conversion, namely, socialization, internalization, externalization, and combination, and also the so-called knowledge conversion spiral where tacit knowledge is "organizationally" amplified through the four modes of knowledge conversion and crystalized at higher ontological levels. Applying the idea of knowledge creation and the concept of GPN (global production network) L. Kim and Ernst (2002) discuss how the latecomer 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 latecomer firms.

It is our view that while there have appeared many empirical and theoretical works on technological development in developing countries, there is still a need for new theories taking into account a new environment including the emergence of digital technology, IT revolution, globalization, and also taking into account the new achievements by Neo-Schumpeterian economics and economics of knowledge. This paper tries to provide a more synthetic account of technological catch-up by synthesizing the stylized facts from empirical and theoretical researches on the catch-up. The focus will be not only on opportunities but also barriers to catch-up, given that catch-up seems to be rather the exception than the rule.

Comment [n.a.7]: Should this be "barriers" instead?

In Section 2, this paper combines the three patterns of catch-up with the sequential pattern of knowledge creation during the stages of technological catch-up, based upon the experience of Korean and Taiwanese firms. The four stages are identified, starting with the first stage mainly involving the latecomers learning skills by socialization of foreigner-held skills, and moving into the second stage of acquiring process technology by internalization of product design; In the third stage, they become able to design imitatively the existing products by externalization of implicit design technology held by specialized R&D firms and personnel abroad, and finally become able to conduct real innovation by creating a new product concept through a combination of domestic and foreign explicit knowledge. It is argued that the first and second stages largely correspond to the duplicative imitation and path-following catch-up, and that the third stage corresponds to creative imitation and stage-skipping catch-up and the final stage, to real innovation and path-creating or leading catch-up.

Comment [n.a.8]: Verify if this refers to "the latecomers."

We note that at every stage, access to foreign knowledge base, in whatever form, is very critical, and thus, Section 3 discusses this issue of access to foreign knowledge base in detail. 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.

As one of the barriers to technological catch-up, the paper emphasizes the uncertainty involved with the third stage, which is something similar to a "crisis" or a critical stage in that the late-comer firms face difficulty as they see many forerunner firms now refusing to sell or give them license and they have to design the product themselves. But, we note that this crisis is also a window of opportunity for the leapfrogging-type of catch-up ("stage-skipping" or "path-creating" catch-up), where the latecomer succeeds in designing its own products. While the existing literature has discussed the facilitating factors for leapfrogging in terms of the three aspects of production capacity, human resources, and locational advantages, this paper emphasizes and discusses in Section 4 the two risks or uncertainty associated with the leapfrogging strategy, namely, the risk of choosing the right technology or standards and the risk of creating initial markets.

Section 5 takes up the issue of whether there can be a common single or several models of catch-up. The possibility of one single model is discussed in terms of some common features in the catching-up process, which is basically to source their high-tech inputs from overseas, to manufacture with high levels of engineering excellence, and to be first-to-market by means of the best integrative designs (Amsden and Chu 2003). The possibility of two models for catch-up is discussed in terms of the key differences between Korea and Taiwan, especially in the position toward the source of foreign knowledge and the paths taken toward the final goal of OBM.

In different parts of the following sections, the paper agues for the importance of the government intervention in the latecomer's technological catch-up, although the exact forms of intervention might change across industry and stages. Also argued is the importance of ownership of the firms as FDIs cannot be relied upon for the technological development of the latecomer 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 play the role of facilitating the adoption of specific standards and thereby influence the formation of markets at the right times.

2. Dynamic process of catch-up and knowledge creation: two issues

The word of reverse engineering was coined to describe the path of technological development of the latecomer firms. It has been observed that in the case of the latecomer firms, they start with the assembly production of final goods using imported parts, then develop low- to high-tech parts, and then learn to design the existing products with some modification, and finally reach the stage of the new product concept creation. This is exactly opposite to the process of product development by the forerunner firms, which start with a new product concept and design then develop parts for it, and finally assemble them. Thus, when one wants to know the level of technological development of the latecomer 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. Along a similar line of thought, Kim (1997a) distinguishes the stages of technological development by dividing them into "duplicative imitation, creative imitation, and innovation stages."

While we can identify different stages along the path of technological development, we can also see there can be different patterns of technological catching-up. 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 of catch-ups (see figure 1). First, there is a path-following catch-up, which means the latecomer 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 latecomer firms follow the path but skip some stage, and thus save time. The third pattern is a path-creating catch-up, which means that the latecomer firms explore their own path of technological development. This kind of catch-up can happen when the latecomers turn to a totally new stage while following 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 catch-up. Without government help, Samsung produced 64 K bit D-RAM chips in the early 1980s. The government's position was such that Korean firms had to start from 1 K bit D-RAM, but it was the private firm's 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.

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[3]. For example, along the path of development of engine technology, we can perceive such stages as fixed line phone (or 1M D-RAM in the case of the 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 product innovations within a given series.

(figure 1 : 3 pattens).

Next, different stages and patterns of technological development can be looked at in terms of knowledge creation along the work of Nonaka. Nonaka and Takeuchi (1995), Nonaka (1994), and Nonaka (1988) identify four modes of knowledge conversion, namely socialization, internalization, externalization, and combination, and also the so-called knowledge conversion spiral where tacit knowledge is "organizationally" amplified through the four modes of knowledge conversion and crystalized at higher ontological levels.

If we combine these four modes of knowledge conversion into the context of catch-up, we observe that the basic pattern of knowledge acquisition in technological catch-up can also be divided into several stages each corresponding to different modes of knowledge conversions. The process, in a simplified way, can be considered as going through the stages of socialization – internalization – externalization – combination. Our basic ideas are expressed in Figure 2. This figure integrates the stages of technology development, the paths of catching-up and the modes of knowledge conversion and the nature of acquired knowledge.

(figure 2: knowledge creation)

According to this figure, during the first stage, the latecomers learn (operational) skills by socialization, or transfer of foreigner-held skills in the mainly assembly type production, and this stage corresponds to duplicative imitation and path-following catch-up. The second stage is to acquire process technology by internalization of product and factory designs provided by the fore-runner firms, and this stage still mainly corresponds to duplicative imitation and a path following catch-up although there is a possibility for stage-skipping catch-up to happen. During the third stage, the latecomer firms become able to design imitatively the existing products or plants and simultaneously learn the related technology by externalization of implicit design technology held by specialized R&D firms and personnel abroad. Since the designs are somewhat different, and often better than, the existing ones, this stage can be considered as involving creative imitation and there is more possibility for stage-skipping catch-up to happen during this stage. Finally, the latecomer firms become able to conduct real innovation by creating a new product concept through a combination of domestic and foreign explicit knowledge, and often establish the cases of path-creating or path-leading catch-up.

In what follows, more explanation is provided on each stage of knowledge creation during the technological catch-up.

1) Socialization stage: learning skills by operating

This is the first stage in technological learning and catch-up, and the catching-up firms learn skills or operational know-how while they produce the final products according to the foreign-supplied manuals on foreign-made plants or production lines. In other words, there is a manual (codified or explicit knowledge) 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 increases through learning by doing, which is the main source for the catching-up during this stage. In terms of catching-up patterns, this stage corresponds to the path-following catch-up.

In terms of the types of knowledge conversion and creation, domestic tacit knowledge (operational know-how and skills) can be said to be created or transferred based upon foreign tacit knowledge (onsite foreign technical guidance) as well as explicit knowledge (manual). Thus, it is, primarily, socialization (transfer) of foreign tacit knowledge converting it to domestic tacit knowledge, and, secondarily, it is internalization of foreign explicit knowledge (manual) to domestic tacit knowledge (see Figure 3).

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 the 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). In other words, the key difference between the first and next stage is the extent to which the local or latecomer firms or entrepreneurs take responsibility for production, and until this stage local responsibility is minimal..

2) Internalization stage: learning processing technology

The second stage of the knowledge creation during the reverse engineering is to acquire processing technology, which means that the latecomer firms now take the responsibility for production. In this stage, the latecomer 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 latecomer firms become capable of *setting up their own production facility and take responsibility for production*.

In terms of knowledge creation, design is a form of codified (explicit) knowledge, which helps the latecomer firms to produce the standardized, final or intermediate, products or helps to set up production facility for it. Thus, in terms of the types of knowledge conversion or creation, it can be said that domestic tacit knowledge (processing technology) is created based upon foreign explicit knowledge (design) as well as tacit knowledge (processing technology). Foreigners provide not only designs but often dispatch personnel to provide technical guidance in setting-up production facility and/or in producing the goods. Thus, we would consider primarily this process as internalization of foreign explicit to domestic tacit knowledge and, secondarily, socialization of foreign tacit to domestic tacit knowledge. Operational know-how or skills acquired during the preceding stage is definitely helpful but not so much critical for successful knowledge learning during this second stage of acquiring processing technology (see Figure 3 below).

In terms of the catching pattern, the stage still corresponds to a path-following catch-up as it basically tries to imitate the forerunner firms. For both the first and second stages, the main form of knowledge learned is tacit knowledge of either skill or process technology. OECD (1996, p. 85 and Table 7.6) also observes that uncodified technologies, which exist as technological information or are embodied in human knowledge, have played a more important role in technology imports than publicly certified industrial property rights, such as patents. Although there might be a possibility for stage-skipping catch-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 catch-up by Hyundai in its development of Pony in 1975 with licensed production of the Mitsubish engine, and, second, stage-skipping catch-up by Samsung in its 64 k D-Ram development; Samsung bought the 64 k dram design from Microelectronics and copied the production facility of Sharp with the help of a small company, which also built the production facility of Sharp before. As mentioned earlier, Samsung decided to skip the 1 to 16 K bit D-RAM to enter directly into 64 K bit D-RAM despite the government advice to start from 1 K bit D-RAM. In the case of Taiwan, many engineers who used to work in a 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 groups took responsibility for their own production with technology licensing agreement with foreign firms.

(figure 3 : details on knowledge creation)

3) Externalization stage: learning how to design existing products

During the previous stages, the forerunner firms provided product or process designs for the latecomer firms. However, as technological capabilities of the latecomer firms grew, there came a time when they felt it was increasingly difficult to buy or get license for the designs held by the forerunner firms who are concerned with the so-called "boomerang effect" of the transferred technology. In this sense, this stage can also be considered as a "crisis" (L Kim 1998) for the catching-up firm. This crisis often serves as a chance for some kind of jump, namely stage-skipping catch-up.

During this stage, which we identify as the stage to learn how to design the existing products, there are products for the latecomers to imitate but there is no design available from the incumbent producers who are reluctant to transfer the design technology. Although the design itself is not available, the latecomers 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 latecomer firms had to rely on the memories of R&D persons previously involved in R&D projects of the forerunner companies to imitate, although with some twist, the existing product design or concept. Of course, the latecomers 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 latecomers develop their own design of an existing product, which is often better than the existing design by the forerunners. For example, Samsung's Silicon Valley R&D team developed a 256 K bit DRAM, which is better than its Japanese counterparts, even if the Japanese refused to give the license for this (L. Kim 1997b).

In terms of the type of knowledge conversion or creation, the stage involves creation of both explicit (product design) and tacit (design technology) knowledge based upon foreign tacit (design technology) knowledge, as well as foreign explicit (literature) knowledge. The primary form of knowledge conversion would be externalization of foreign tacit to domestic explicit knowledge and, secondarily, socialization of foreign tacit to domestic tacit knowledge and also internalization of foreign explicit (literature) to tacit knowledge. Of course, the acquisition of new knowledge during this stage is based upon process technology-related knowledge acquired from the preceding stages, and the importance of the pre-existing domestic knowledge base has increased compared to that of the preceding stages (see figure 3 above).

Here, we would like to emphasize the importance of the unique nature of "imitative externalization" for catching-up firms during this stage. According to Nonaka and Takeuchi (1995, p. 66), externalization holds the key to knowledge creation, because it creates new, explicit concepts from tacit knowledge. In the case of catching-up during this stage, externalization replicates existing concepts with the help from foreign tacit technology. That is the reason we call this "imitative externalization" as it often relies on the memories of R&D persons previous involved in R&D projects of forerunner companies to imitate, although with some twist, the existing product design or concept. However, this is creative imitation as it often results in better products than the existing products by the forerunners, and thus often involves stage-skipping catch-up.

We can give several examples of this stage. First, there is the case of Hyundai Motors which had to develop its own engine called "Alpha" during the period from 1984 to 1992 when Mitsubish refused to transfer its latest engine technology. This case is an example of "stage-skipping" catch-up. When Hyundai started to develop the engine, the carburetor-based engine was the standard type. But, knowing that the trend of engine technology was moving into a new electronic injection-based engine, Hyundai decided to develop the latter-type engine, rather than following the old track in developing the standard type. By succeeding in this project, Hyundai was able to reduce the gap in engine technology in a very short period of time.

Second, Samsung chose to develop its own design technology for 256 K or higher (up to 64 mega) bit Dram as it was not easy or cheap to buy the design. After Samsung's success with the development of designs for 256 k bit DRAM, some foreign companies were willing to sell 1 mega bit DRAM designs but Samsung declined to purchase them since it thought it could develop it on its own (Kim 1997). In other words, Samsung skipped the pre-256 K bit D-ram stages in its development of design technology.

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 which paved the way to notebook and cell phone in later period (Amsden and Chu 2003, p. 28-32). Young, Taiwan-educated engineers have 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 have mastered the skill of design integration, which enabled them to be the first to market (if not the 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 vendors, 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.).

Comment [n.a.9]: This should have been mentioned earlier in this paper, and therefore may be omitted here.

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 government research institutes, such as the ITRI (Industrial Technology Research Institute). A notable example is the public-private R&D consortium to develop laptop PCs, which ran for a year-and-a-half from 1990 to 1991(Mathews 2002). This consortium with a capital of less than two million US dollars had 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) Combination stage: learning by developing a new product

For this final stage of knowledge creation in technological catch-up, there is neither "design" of a product nor the product itself to imitate. That means that the latecomer has reached the final stage of catch-up, to create a new product based on new product concepts. But, more often than not, any innovation is not an outcome of totally indigenous R&D effort as the latecomers still need access to external knowledge base to get some critical core technology. The difference lies in the mode of access to core technology as it can now be co-development with the world's top leading companies in the field, usually small venture companies that have their own source technologies but lack financial resources to conduct large-scale and risky R&D projects.

It is during this stage of knowledge creation that for the first time the process involves combining domestic and foreign bodies of explicit knowledge, whereas the role of domestic explicit knowledge was negligible in the preceding stages. A foreign body of explicit knowledge is some core or source technology (or patents) held by foreign R&D partners or in the related literature, and domestic explicit knowledge is the design of the existing products and the related patents acquired during the preceding stages. In other words, in this stage, domestic knowledge, both explicit (design of new product) and tacit (enhanced processing technology), is created based upon the existing domestic, tacit and explicit knowledge, as well as foreign explicit knowledge.

Thus, in terms of the types of the knowledge conversion, it is primarily a combination of foreign explicit with domestic explicit knowledge, and, secondarily, creative externalization of domestic tacit to domestic explicit knowledge. In this process of knowledge conversion, the externalization process can now be called "creative externalization" of domestic tacit knowledge for a new product concept. Also to be noted is that creation of a new product concept is a joint product of this creative externalization and foreign plus domestic combination. In this stage, acquisition of new knowledge is based upon domestic knowledge base consolidated over the preceding stages and its role is important as it is different from the preceding stages. Although the combination is said to be a primary form of knowledge conversion, all diverse channels of knowledge conversion is utilized for a richer knowledge creation in this stage (see Figure 3 above).

Since this stage is for real innovation, it is often accompanied by path-creating or leading catch-up as seen in the following examples. First, we have an example of a path-creating catch-up that the Korean consortium led by the ETRI, first time in the world, developed and commercialized the CDMA system for wireless telecommunication (Lee and Lim 2001). It was an outcome of co-development contract with the US-based venture company, Qualcomm. The second example can be the world's first development of 256 mega DRAM by Samsung, which can be considered as a "path-leading" catch-up. Actually, it was motivated by the public-private collaboration aimed specifically at development of 256 mega D-RAM, which required enormous R&D money and risk, and initially hesitant private companies including Samsung were pushed by the initiatives by the GRI (government research institute), the ETRI. The third example is the digital TV development by Samsung and LG, which is analyzed in detail in Lee, *et al*. (2005).

Comment [n.a.10]: Would it be correct to change this to "ETRI, a government research institute" ?

5) The two issues: knowledge access and the push factor for leapfrogging

The discussion of the four stages shows that before the catching-up reaches the final stage of real innovation, it has been basically foreign to domestic conversion of knowledge, but not indigenous domestic-to-domestic knowledge conversions leading to the spiral. This implies that at every stage, access to foreign knowledge base, in whatever form, is very critical, which also signifies the weakness of the knowledge-creating mechanism of the latecomer firms and the need to consolidate the domestic links and spiral. This feature of the Korean knowledge base can also be called as “a narrow domestic knowledge base” if we borrow it from Ernst (2000). Case studies of catch-ups, such as Lee and Lim (2001), Lee, et al. (2005), and Mu & Lee (2003), as well as quantitative analysis using patent data, all indicate the crucial role of knowledge access in catch-ups. Thus, the next section will discuss this issue of access to foreign knowledge base in detail.

Second, among the four stages, we want to emphasize the importance of the third stage where the catching-up firms have to develop their own designs for the products. They have to do so since the forerunner firms decline to sell or give license of the designs for fear of the possible boomerang effects. In this sense, this stage can be considered as a "crisis" at the successive growth of technological capabilities of the catching-up firms. The task facing the catching-up firms is to develop product designs on the basis of the previously accumulated operational know-how and processing technology. It is to externalize tacit knowledge (processing technology) into explicit knowledge (designs), and is not an easy task as emphasized by Nonaka and Takeuchi (1995, p. 66); externalization holds the key to knowledge creation. However, as noted in the literature (Lee and Lim 2001; Lee, et al., 2005), several Korean firms overcome, or rather took advantage of, the crisis to achieve leapfrogging of stage-skipping or path-creating catch-up. The point is that the crisis served rather as a push factor to seek new breakthroughs and eventually a window of opportunity for leapfrogging. The section after this following section will discuss the issue of leapfrogging.

3. Diverse channels of access to foreign knowledge in catch-up

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 latecomer 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 catch-up economies. Hence, the extent of spillover from advanced countries to catch-up economies in each sector has importance for catch-up.

A quantitative study using the patent data has proven, comparing the level of technological capability of the advanced and catch-up economies, that catch-up countries tend to achieve high levels in the sectors with easier access to knowledge (Park and Lee 2004). Case studies in Lee and Lim (2001), Lee, Lim and Song (2005), and Mu and Lee (2004) all confirm the importance of access to the external knowledge base, namely, the issue of technology transfer although specific channels are different in different industries. The alternative channels include informal learning, licensing, FDI, strategic alliance, co-development, and so on.

Licensing versus FDI

One issue in technology transfer is the relative superiority of licensing versus FDI. In the early days of industrialization, onsite instructions from the buyers in OEM export contract were important in Korea. Other than this, the main forms of technology transfer were 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 catch-up in 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 closer 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 Semiconductors show, small R&D specialist companies in the advanced can be a source of 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, notable in the 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, such as 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 be another source of new knowledge to the local indigenous firms and R&D units trying to absorb new knowledge. However, it should be noted that successful indigenous R&D did occur not at the JV itself but in other local firms and people who purposely absorbed knowledge from the JVs through the mobility of engineers and scientists, onsite observation and learning, and even the participation at the adaptation process of foreign-made products in China (Mu and Lee 2003).

These experiences in Korea and China suggest that merely following the FDI strategy from beginning to end is not likely to generate a stage-skipping or path-creating catch-up. However, having such JV in a locality give the neighboring latecomer firms some window of learning and imitations as the experience of Taiwan suggests. In the early days of industrial development, foreign firms 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).

In-house R&D and pubic-private R&D consortium

Along the path of development, the latecomer firms soon reach the stage where 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-fold (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 result, Korean firms keenly recognized the need to develop their own technological capabilities. Third, government policy to support private R&D also changed. 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 has accounted 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 latecomer 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 2003). 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 the consortium to develop digital TV in Korea show that collaboration and knowledge sharing among the private firms have certain limits within the framework of consortium because of the intrinsic rivalry among them. 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 a 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 are 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 which identified the small firm like Qualcomm as the R&D partner and carried out R&D activities, and the KITECH and ETRI that carried out R&D activities and coordinated the consortium of the research projects in two specific fields of the whole project.

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 ready-to- -use state in factories (Perez & 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 latecomer 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 is relatively low, as their capacity grow high enough to have some horizontal collaboration, having complementary asset becomes more important.

In the case of CDMA mobile phone development, the collaboration between Qualcomm and the Korean consortium was possible because each side needed something from the other side (Lee, et al., 2005): the Korean side 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 the same as that of analog TV. R&D units in the advanced countries 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 forerunner firms is possible only when the latecomer 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, seem to be important in these new ways of accessing knowledge.

Sequential changes in access modes to knowledge:

The above discussion 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. The key technology is embodied in imported machinery and equipment. It is basically learning by doing with no capacity or even intention for planned technological development. In the late 1960s and 1970s in Taiwan, engineers learned skills by working in American firms or in joint ventures with Japan (Amsden and Chu 2003).

In the next stage, when the latecomer firms recognize the need for more systemic learning and planned technological development, such firms tend to resort to technological licensing and actively seek 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 monitor industry in the 1980s, which emerged after the television industry of the 1970s, the main channels were licensing or joint ventures (Amsden and Chu 2003). In this stage, the critical factor for effective learning would be absorption capacity of the latecomer firms, which also depended on the education system and other elements of the national innovation system of the country. In some cases, the distinction between the first two stages might not be that clear.

In the next stage, the latecomer firms establish a certain degree of in-house R&D capacity with a clear idea of what should be done how, and with how much resources to be allocated. With licensing or learning from foreign partners revealing its limits, the latecomer firms now should rely on public-private R&D consortium, 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 the government laboratory 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, such as Samsung, have reached this stage, and are now engaged with Intel, Sony, Toshiba, and MS in diverse modes of alliances.

4. Push and pull factors for leapfrogging

1) Crisis leading to leapfrogging: the push factors for leapfrogging

The preceding section indicated that the basic pattern of knowledge acquisition in the reverse engineering can be divided into several stages, and that although each stage involves diverse channels of knowledge conversions, the process, in a simplified way, can be considered as going through the stages of socialization – internalization – externalization – combination. In others, at the first stage, the latecomers learn skills by socialization of foreigner-held skills, then, acquire process technology by internalization of product design during the second stage. In the third stage, they become able to design imitatively the existing products and simultaneously learn the related technology by externalization of implicit design technology held by specialized R&D firms and personnel abroad, and finally become able to conduct real innovation by creating a new product concept through a combination of domestic and foreign explicit knowledge.

Among the four stages, I want to pay more attention to the third stage, which is something similar to a "crisis" or a critical stage where the latecomer firms face difficulty as they see many forerunner firms now refusing to sell or give them licenses. During the previous stages, the forerunner firms provided product or process designs for the latecomer firms. However, as technological capabilities of the latecomer firms grew, there came a time when they felt it was increasingly difficult to buy or get license for the designs held by the forerunner 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. This crisis can be a momentum for "stage-skipping" or "path-creating" catch-up as it serves as a window of opportunity for leapfrogging.

2) Leapfrogging to grab the opportunity of new paradigm

While the above discussion suggests that the pressure to have one’s own design capability might lead to leapfrogging, the emergence of a new technology paradigm can also bring new opportunity for latecomer firms to exercise leapfrogging. The argument on the advantages of catching up countries goes back to Gerschenkron (1962, 1963) who 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 afterthey become mature enough to have the capital goods suitable for efficient production. However, this discussion was confined to the catching up in the mature technology. Freeman and Soete (1997) and Perez and Soete (1988) 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 be disadvantages for the established firms and advantages for 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 advantages for 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 equipment to produce new industry goods are not developed yet, and production volume is small, general-purpose machines should be utilized. Therefore the entry barrier associated with economy scale does not exist. Second, in the initial stage of the 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 because of the sunk costs of their investment.

3) Two risks with leapfrogging

While the existing literature has discussed the facilitating factors for leapfrogging in terms of the three aspects of production capacity, human resources, and locational advantages, this study rather emphasizes 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.

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 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 the 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 USA or in the EU even before the market was formed. In the case of CDMA, the TIA (Telecommunications Industry Association) adopted CDMA as the North American digital standard owing to Qualcomm's efforts in 1993 before any market toward CDMA communication was 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 USA 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 early entrants and hence the catch-up by late-comers. What the catch-up firms, like Korean firms, should do is simply to develop products compatible with that standard although the details are more complicated than this.

Risk of initial market creation

When the latecomer firms go along the path of leapfrogging, one of the risks would 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 try to go along the uncertain and risk technology of CDMA. However, the government declared the CDMA as the national standard 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 latecomer countries) upon the new or successful development of key capital goods by the latecomers, whereas they have been charging high or monopoly prices for the same goods as there used to be no competitive suppliers in latecomer countries. There are numerous such cases between the Japanese firms exporting core parts and equipment 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 are incentives provided 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 2003). The basic role of the Chinese 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 effect, the figure reached 84.8% in 1996, and in 1997, reached over 90%, or 94.9% to be exact.

Since 1997, the MPT (ministry of post and telecommunications) has 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 (Xin and Wang, 2000) as they gave huge orders for Chinese firms, such as Huwei. (Xu and Fu, 1997). Also, under the encouragement of the People's Bank of China, the China Construction Bank supplied indigenous firms a big amount of buyer credit.[4] Affected by the coordinating conferences and financial support, since 1998 the market share of the indigenous firms has increased rapidly, and they became the main suppliers in the domestic market (Mu and Lee 2003).

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, the 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 who share the same technological standards. Since cultivation of big enough 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 putting 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 creates and gets 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 facilitate the adoption of specific standards and thereby influence the formation of markets at the right times.

5. One, two or three pathways to catch-up: Korea, Taiwan and China

1) One successful catch-up model?

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 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 number 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 latecomer as the fast second mover is closely coupled with production and detailed design (Amsden and Chu, 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 the

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

competitiveness of the catching-up firm depends on its ability to enter new market 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 in Park and Lee (2004).

[table 1: catch-up sectors]

With Table 1, this study confirms that Korea and Taiwan have achieved higher levels of technological capabilities in such sectors with features such as 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 latecomers.[5] This observation is consistent with the findings by Albert (1998), from his study on patenting trends in the USA that Taiwan and Korea emphasize fast commercialization of information technology, as the patents by these countries show much shorter technology cycle time than those in Japan and cite less scientific literature.[6] Although what the latecomer firms developed is a new product, it was made 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 latecomers and can permit leapfrogging by developing countries.

Given the strategy of outsourcing core source technology from overseas, the importance of access to foreign knowledge is also shared by both Korea and Taiwan. The regressions in Park and Lee also confirm this as knowledge accessibility variable has turned out to be positively related with the level of technological capability of catching-up economies but is negative and not significant in the case of the advanced countries. This implies that the catching-up record is sensitive to the access to knowledge, whereas the advanced countries are not sensitive to the access to knowledge. Appropriability variable is also not significant in the case of the advanced countries but is significant and positive in the case of the catching-up economies. This implies that given the limited resources for R&D, the latecomer firms from the catching-up economies tend to focus on those sectors where they enjoy the fruit of innovations more easily and securely.

While extensive diversification has been noted as the hallmark of Korean chaebols, Amsden and Chu (2003) observed the same tendency of diversification in Taiwan. They argue that because innovation in catching-firms meant being the first locally to apply known or borrowed technology, notebook companies and cell phone companies tended to be the same (p. 61). The Korean and Taiwanese firms are the same in the sense that their core competences are not product innovation using world's first knowledge but a combination of production engineering, project execution capability, and detailed designing.

The above discussion suggests that there is only one model for successful catch-up. However, although Korea and Taiwan faced the same task of catch-up and both made success, the evolutionary path of each country was so different as to be able to say there are at least two

[5] 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.

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

models of catch-ups.

2) Possibility of two models?

First of all, the difference in terms of firm-size structure of the two economies is replicated in technological structure. For instance, about two-thirds of the US patents held by the Koreans are registered by the top five chaebols with Samsung alone accounting for about one-third of the recent US patents by all the Koreans, whereas about two-thirds of the US patents by Taiwanese are registered by individuals (or owners of the SMEs). Examination of the sectors with the largest number of US patents registered by Korea and Taiwan also show that while Korea did well in the electric and electronics and the computer and communication sectors, Taiwan did well mainly in the mechanical sector. Overall, the top ten sectors are all different between the two countries (see Table 2).

[table 2]

Park and Lee (2004) examine the linkage between the technological regime and catch-up performance using the US patent data of Korea and Taiwan to see the differences between these countries in terms of the sectors doing better in each of them. What this study find is that Korean firms has made a technological catch-up in sectors of low appropriability, high cumulativeness (persistence), and a smaller stock of cumulative knowledge, whereas Taiwanese firms achieved technological catch-up in sectors of high appropriability, low cumulativeness (persistence), and a large stock of cumulative knowledge. The interpretation regarding appropriability is that given the smaller size and R&D capacity, Taiwanese firms tend to try to specialize in a narrow area and pursue cooperative R&D instead, compared to diversified large firms (Choung and Hwang 2000); and given these characteristics, those sectors allowing much more and secure reaping of previous innovation outcomes should be a safe choice for them. Also in these sectors, they could have less worry about the possible leakage of their technology to large firms and thus about the possibility of being competed out by the large firms. A similar logic holds for cumulativeness. In light of catch-up countries' perspective, higher cumulativeness (persistence) can be regarded as a sort of direct competition with large advanced firms. It is because, in sectors of high cumulativeness (persistence), large innovative firms tend to dominate the technology and market. In technological regimes where technological advances take place in a cumulative way, innovative entrants find themselves at a major disadvantage with respect to incumbents (Winter, 1984; Breschi *et al*., 2000). Then, our results indicate that the Korean chaebols are not as sensitive to cumulativeness as the SMEs in Taiwan.

However, for smaller firms like in Taiwan, cumulativeness poses a more serious disadvantage for them. For these high cumulative sectors, they would rather take the strategy of depending upon the big MNCs or public R&D institutes by being integrated with them. In contrast, for the firms pursuing independent R&D strategy like Korean firms, a larger stock of cumulative knowledge acts as a barrier to speedy catch-up, as shown by the negative sign of the initial stock variable for Korea.

As argued by Swann and Gill (1993) and Kim and Lee (2003), this divergence between the two countries is consistent with the organizational selection hypothesis that the firms of different organizations show divergent degree of fitness in the different environment or technological regime. The Korean firms, dominated by so-called chaebols especially in patent registrations, are characterized as less flexible and large diversified conglomerates and pursuing more independent R&D and learning strategies. Taiwanese firms are characterized as more flexible and network-based and pursuing more cooperative R&D and learning strategies. Thus, the Korean firms feel as a more serious barrier the larger stock of knowledge at the beginning period and its faster increase, whereas the Taiwanese firm has established more cooperative learning channels with the MNCs serving for them as lower tier producers, and thus are good at taking advantage of spillover from the forerunner firms.

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 and Trajtenberg (1993), Lee and Yoon (2004) test whether or not knowledge diffusion among the firms in Taiwan was stronger than among the firms in Korea. They measure localization by the extent in which the citing patent of a country cite the patent of same country, rather than following an alternative of measuring it as the extent of the original patent of a country cited by the same country. This study has basically confirmed the hypothesis that the level of localization is higher in Taiwan than in Korea, and that while Korea achieves localization of knowledge flows mainly through internalization of knowledge flows within its own firms, Taiwan achieves localization of knowledge flows mainly through interaction between firms. To put it simply, the examination of citation pattern in patent filing show that Korean chaebols firms do not cite each other's patents, while Taiwanese firms cite each other's patents more intensely.

If we examine the role of government research organizations in the intra-national knowledge diffusion, the contrast becomes more interesting (Lee and Yoon 2004). In the semiconductor industry, in the case of Korea, most of DRAM 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 3] and [Table 4]. That is, in the case of Korea, the first patent grant was not by the ETRI, a Korean 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 the 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 4] represents 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 3 and 4]

While there are few patents by the ETRI in semiconductors, this does not necessarily mean that the role of the government or the GRI (government research institute) were 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 during the later or development stages, 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 complementing role, whereas the Taiwanese government had played a critical role particularly in mitigating risks faced by firms in the early stage of R&D.

The above discussion suggests 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]

The Korean path is led by a few large firms which 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 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 of new knowledge in the form of embodied technology importations, licensing, co-development, and horizontal collaborations. On the other hand, these chaebols are also independent from each other, without much collaboration or exchange of knowledge among them. In contrast, each chaebol, behaving like a flagship firm, has brought up and maintained its own network with subcontracting or collaborating firms.

The Taiwanese 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 in 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 spin-off firms from the government sector. On the other hand, these Taiwanese firms are in intense

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

collaboration or exchange of knowledge among themselves. The network in Taiwan, as typically observed in electronics was a geographical agglomeration consisting of firms 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.

3) The common dilemma and policy issues

The key difference between Korean and Taiwan seems to be in the modes of access to foreign knowledge. The Taiwanese firms have followed the steps of the OEM, ODM, and OBM (Mathews 2002; 2003) whereas Korean chaebols did not take the path and, from the beginning, conducted the business with their own brand. In a sense, the Korean chaebols skipped the ODM stage as they used to be the final assemblers 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, did they (Korean firms) realize 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. It was only from the 2000s that 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 merely 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, merely 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 was quite difficult, which is the common dilemma for both Korean and Taiwanese firms.

Koran chaebols soon realized that the forerunner firms were no longer willing to give them designs, and thus this constituted the crisis stage in the dynamic path of technological development discussed in Section 2. For the Taiwanese firms, the crisis unfolded as the foreign vendor switched to other lower-wage economies, such as Malaysia, for their OEM orders as wage rate increased in Taiwan. They realized that they needed to have the capability to create their own design 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, p. 77).

Korean chaebols overcome this crisis 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 Taiwanese firms of smaller scale, the solution was the "new developmental state" with its import substitution policies. The latecomer 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 p. 77).

This suggests the continuing importance of the government intervention in the latecomer's technological catch-up, although the exact forms of intervention change over time (Amsden and Chu 2003). Also, the fact that in the final stage of catch-up, the nationally owned firms has eventually emerged as the leader of the industry even in Taiwan, suggests the important of ownership of the firms in technological catch-up. The FDI firms cannot be relied upon for the technological development of the latecomer countries, although they can serve as initial learning places. As Amsden and Chu put it (2003, p. 3), technological catch-up requires using assets related to project execution, product engineering, and a form of R&D that straddles applied research and exploratory development, and if such assets are to be accumulated at all, the responsible party tend to be nationally owned organizations. By its nature, the FDI firms have no reason or incentives to develop their own development capabilities, which reside in the mother companies abroad. In sum, ownership matters at least in R&D.

This observation on the role of the FDI or international subcontracting does not mean that the latecomer 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 Taiwanese 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 latecomer firms have become able to command 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 in acquiring design and product development capability, what is needed is more "creativity." Here lies 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, similar to the NASDAQ in the USA. Only two years after its establishment, KOSDAQ has emerged as the mother of hundreds of small- and medium-sized venture companies and start-ups. Many ambitious youths were joining KOSDAQ firms from universities and many talents are leaving the giant 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.

Finally, it is interesting to know which pattern will prevail in the rapidly catching-up country of China. Roughly speaking, China might be a third model mixing both Korean and Taiwanese models into one. China has developed a large segment of industries dominated by FDI from neighboring economies of Asia, e.g., 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 hand, 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 only 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.

Comment [n.a.11]: Verify if this is the correct spelling.

Comment [n.a.12]: Should this be "Konka" instead?

Comment [n.a.13]: Verify if this is correctly stated, or if this should be "Fortune 500 Global firms" instead.

8. Summary and conclusion

This paper first provides a discussion of the sequential pattern of knowledge creation during technological catch-up, based upon the experience of Korean and Taiwanese firms. During the first stage, the latecomers learn skills by socialization of foreigner-held skills in mainly assembly-type production, and the second stage is to acquire process technology by internalization of product designs provided by the forerunner firms. During the third stage, the latecomer firms become able to design imitatively the existing products, and finally, the latecomer firms become able to conduct real innovation of creating a new product concept.

As one of the barriers to technological catch-up, the paper emphasizes the uncertainty involved in the third stage, which is something similar to a "crisis" or a critical stage where the latecomer firms face difficulty as they see forerunner firms now refusing to sell or give them license and they have to design the product themselves. But, we note that this crisis is also a window of opportunity for leapfrogging-type catch-up ("stage-skipping" or "path-creating" catch-up), when the latecomer succeeds in designing its 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 as it serves as a window of opportunity. While the existing literature 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 the right technology or standards and the risk of creating initial markets.

The discussion of the four stages of knowledge learning also shows that before the catching-up reaches the final stage, it is basically foreign to domestic conversion of knowledge, but not indigenous domestic-to-domestic knowledge conversions, and that at every stage, access to foreign knowledge base, in whatever form, is very critical. 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. The key technology is embodied in imported machinery and equipment. In the next stage, such firms tend to resort to technological licensing and actively seeking learning or transfer from any FID partners. In the third stage, the latecomer firms establish a certain degree of in-house R&D capacity, which is to be supplemented by public-private R&D consortium, overseas R&D outpost, 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 common single 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 to source their high-tech inputs from overseas and thereby create their scarcities in other inputs, design or functions when a "new" mature productis still hot (Amsden and Chu 2003, p. 163, 167). While the private R&D of the first mover includes basic or some applied research, that of the latecomer as the fast second mover is closely coupled with production and detailed design. Thus, a common element of catching-up is to enter new market 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 have achieved higher levels of technological capabilities in such sectors 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 becomes quickly obsolete, catch-up more likely occurs is consistent with the insights of leapfrogging, which states the paradigm changes serve as a window of opportunity for latecomers.

The possibility of two models for catch-up is also discussed in terms of the key difference between Korea 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 firms in Fortune global 500 'as of 2000. In Taiwan's case, the disadvantage of being small and the need for technological breakthrough had to be overcome by deliberate government intervention in R&D, which led to spin-offs and technology transfer to private firms. In the Korean case, for large and risky project, public-private R&D consortium played an important role as seen in the list of such cases as TDX in the 1970s, CDMA in the 1980s, and digital TV in the 1990s.[8]

Comment [n.a.14]: Should this be "Fortune Global 500?"

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Based on the discussion of many cases, the paper argues for the importance of government intervention in the latecomers' technological catch-up, although the exact forms of intervention might change across industry and stages. Also argued is the importance of ownership of the firms as FDIs cannot be relied upon for the technological development of the latecomer countries although they can serve as initial learning places. 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 play the role of facilitating the adoption of specific standards and thereby influencing the formation of markets at the right times.

[8]. The 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.

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Table 1: Sectoral determinants of technological catch-up and capability

Variables	Level of Technological Capability		
	Advanced countries.	Two Catch-up countries	One hypothetical. catch-up country
OPPORTUN	0.401	1.662	0.033233
	(1.630434)	(2.48759)	(0.041539)
CUMUL	-3.299	-2.071	-0.04142
	(1.329671)**	(0.961164)**	(0.018969)**
APPRO	-1.99	10.583	0.211664
	(1.924043)	(2.587189)***	(0.048263)***
ORIGINALITY	-2.865	-0.037	-0.00073
	(1.659448)*	(1.259217)	(0.025281)
UNCERTAIN	0.003	-0.004	-0.000072
	(0.005922)	(0.002909)	(0.0000427)
INITIAL	0.635	-0.217	-0.00433
	(0.395755)	(0.34321)	(0.006131)
CYCLE TIME	8.193	-3.529	-0.07057
	(1.077178)***	(1.034245)***	(0.020791)***
ACCESS	-5.065	17.011	0.34023
	(7.119563)	(7.353109)**	(0.14069)**
R-squared	0.52181	0.1379	0.192837
Adjusted R-sq.	0.51873	0.12744	0.175243
F-statistic	169.773	13.1873	10.95989
No. of observations.	1880	752	376

Source: Park and Lee (2004).

Notes: The two catch-up countries are Korea and Taiwan, and one hypothetical catching-up country is defined by the sum of patent shares of the two catch-up economies. The dependent variable is the share in the US patents registered, and the independent variables represent the characteristics of each sectors in the US patent classes divided into 470 sectors. More detailed explanations are also here.

Table 2: Sectors that show a high degree of catch-up by Korea and Taiwan

Class	Sectors
	Korea
68	Textiles: Fluid Treating Apparatus
386	Television Signal Processing for Dynamic Recording or Reproducing
353	Optics: Image Projectors
348	Television
438	Semiconductor Device Manufacturing: Process
365	Static Information Storage and Retrieval
445	Electric Lamp or Space Discharge Component or Device Manufacturing
360	Dynamic Magnetic Information Storage or Retrieval
332	Modulators
62	Refrigeration
	Taiwan
190	Trunks and Hand-Carried Luggage
482	Exercise Devices
12	Boot and Shoe Making
135	Tent, Canopy, Umbrella, or Cane
81	Tools
70	Locks
160	Flexible or Portable Closure, Partition, or Panel
16	Miscellaneous Hardware
362	Illumination
301	Land Vehicles: Wheels and Axles

Source: Park and Lee (2004)

[Table 3] 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 4] 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)

Figure 1 : Three Patterns of Technological Catch-up

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

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

e.g.) Consumer electronics during the analog era, PC, Machine tools

Stage-skipping Catch-up: stage A ---------------> stage C --> stage D

(leapfrogging I) e.g.) automobile (engine), D-RAM, Telephone Switches (China)

Path-Creating Catch-up: stage A --> stage B --> stage C' --> stage D'

(leapfrogging II) e.g.) CDMA mobile phone, Digital TV

Notes: In stage C, the two technologies, C and C', represent alternative technologies

Figure 2 Patterns of Catching-ups and Stages of Reverse Engineering and Knowledge Creation

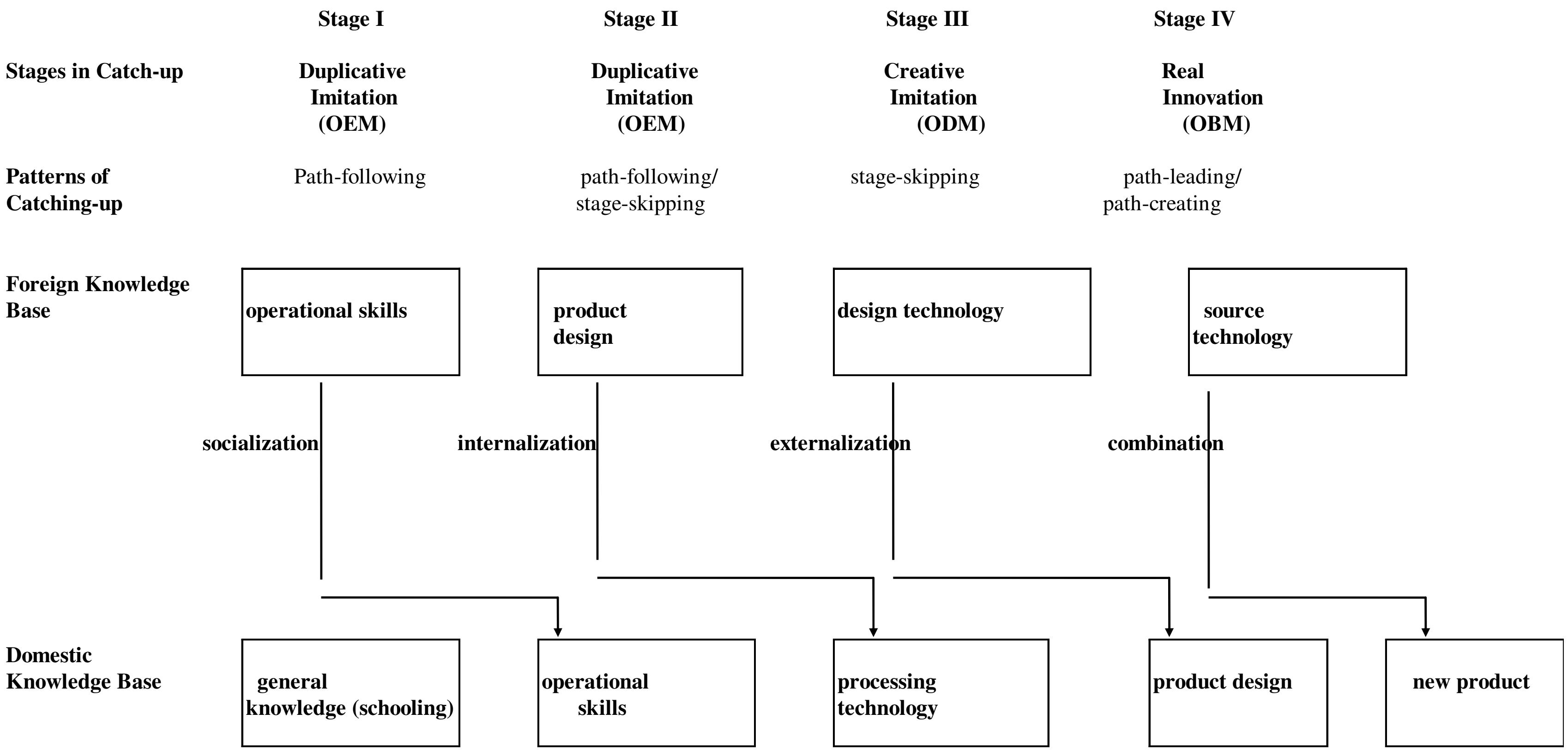
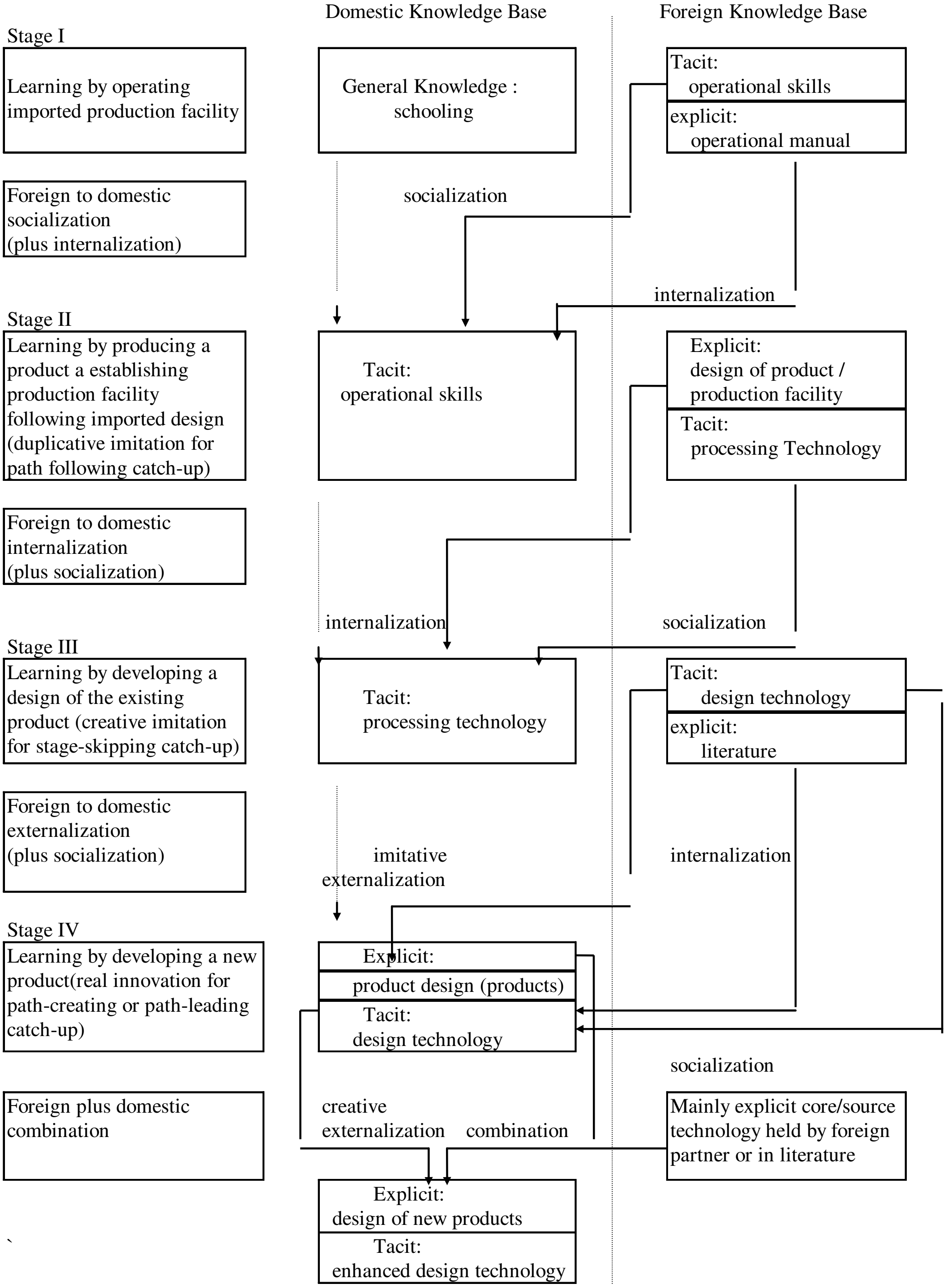


Figure 3 : Stages of Knowledge Creation for Technological Catch-up



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