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Linking the Technological regime to the Technological Catch-up: An Econometric Analysis using the US patent Data

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Abstract

This paper conducts an econometric analysis of the relationship between the technological regime and the possibility and degree of technological catch-up, using U.S. patent data. In this work, we have identified new element of the technological regimes that is relevant in the context of catch-up, and they are access to external knowledge flows, uncertainty or fluidity of technological trajectory, initial stock of technological knowledge, and technological cycle time.

This study has confirmed the basic hypothesis that different elements of technological regimes have different implications for the technological catch-up and hence for building technological capability. One of the more robust and specific findings is that longer cycle time of technology of a sector implies a lower possibility and degree of technological catch-up and hence lower level of technological capability attained by catching-up economies. To put it simply, this finding imply the window of opportunity opened up by the rapid technological change as asserted by the leapfrogging argument.

The study also confirms the organizational selection hypothesis such that the firms of different organizations and strategies show divergent degree of fitness in the different environment or technological regime. We find that the Korean firms find themselves less fitted in such environment featured by high fluidity and rapid increase of knowledge, and they made a catch-up in sectors of low appropriability and high cumulative (persistence) dominated by advanced firms whereas the Taiwanese firms less fitted, by low spillover and achieved technological catch-up in sectors of high appropriability and low cumulativeness (persistence). Our findings are consistent with the following characterization of the firms in Korea and Taiwan. The Korean firms, dominated by so-called Chaebols especially in patent registrations, are characterized as less flexible and large diversified conglomerates and pursing more independent R&D and learning strategies. Taiwanese firms are characterized as more flexible and network-based, specialized and pursing more cooperative R&D and learning strategies.

1. Introduction

Catching-up economies, in particular Korea and Taiwan, achieved remarkable growth in a few decades. Although these countries have promoted technological development in general, this fact does not hold nor does it have the same meaning throughout all technological sectors. Some sectors achieved remarkable technological catch-up, while others did not. How can the difference between sectors be explained? And what were the conditions affecting the occurrence of and the degree of technological catch-up?

Like Lee and Lim (2001), this paper gives attention to the technological regimes of specific sectors. Lee, Lim and Song (2004) and Lee and Lim (2001) attempt to link the neo-Schumpeterian notion of the technological regime (Breschi *et al.*, 2000; Malerba, 2002; Malerba and Orsenigo, 1996, 1997; Breschi and Malerba, 1997) to the leapfrogging thesis in examining the experiences of some selected industries in Korea. They aim to identify the stylized facts in the process of technological capability building and catching-up, and thereby, sort out the conditions that enabled catching-up to occur. Lee and Lim (2001) argue that technological regimes affect the innovative activities of catching-up firms and hence the chance for successful catching-up.

Although Lee and Lim (2001) show the possibility of relating the phenomenon of catch-up to technological regimes, their study is limited to case-studies of selected industries. Building on their work, we aim to analyze the link between technological regimes and technological catch-up through an econometric method using patent data. To this end, we develop various proxy variables to represent aspects of the technological regimes of sectors by using the US patent data and patent citation data. That is, using patent data, we try to develop a quantitative expression of technological regimes and investigate 1) in which sectors (or sectors of which technological regimes) technological catch-up tends to, or tends not to, occur and 2) what affects the degree of technological catch-up.

With this method, we analyze the determinants of several aspects of technological catch-up in two typical catching-up economies – Korea and Taiwan. These two countries are chosen as typical catching-up economies since we define catching-up economies as those whose patent registration growth rates are higher than the average of the G6, given the total number of patents larger than a sort of threshold. During 1975-1999, 12 countries cumulatively registered more than 10,000 patents, and only Korea and Taiwan had made more rapid accumulation of patents than the G7. While the average growth rate of G6 is 3.25, Korea and Taiwan registered 31.79 and 23.09 respectively. Actually, Korea and Taiwan have been acknowledged in the literature as having experienced rapid industrialization and technological upgrading, and can thus be considered as typical catching-up economies.

Our analysis focused on the two aspects. We first examine the phenomenon of technological catch-up by distinguishing between the *possibility* of technological catch-up and the *degree* of catch-up. We then conduct regression analysis to find the determinants of each of these two aspects of technological catch-up. Second, we analyze the determinants of the levels of technological capability in catching-up economies and compare them with those in advanced countries.

This paper proceeds as follows. Section two examines the literature, discusses the theoretical framework of analysis, and suggests hypotheses for empirical verification. Section three discusses the data sources and presents the structure of regression models. Section four contains the results of the empirical analysis, and section five provides a summary and concluding remarks.

2. The Theoretical Framework and the Hypotheses

1) The Concept of the Technological Regime

The concept of the technological regime was introduced by Nelson and Winter (1982) as an intellectual framework for interpreting the variety of innovative processes observed across industrial sectors. Technological regimes draw a link between the various aspects of the innovation process and organize inter-industry differences into a few invariant categories (Marsili and Verspagen, 2001). The notion of the technological regime defines the nature of technology according to a knowledge-based theory of production. In this, innovation is regarded as a problem-solving activity drawing upon knowledge bases that are stored in routines.[1] In this way, a technological regime defines the particular knowledge environment where firm problem-solving activities take place

1 Sectoral asymmetries in industrial dynamics can be interpreted on the grounds of technological regimes (Nelson and Winter, 1982).

(Winter 1984). Technological regimes are important because they constraint the pattern of innovation emerging in an industry. Technological regimes refer to the rules that guide the design and further the development of a particular technology. And a technological regime sets the boundaries to what can be achieved in the problem solving activities associated with a given set of production activities, and the directions (natural trajectories) along which solutions are likely to be found (Marsili and Verspagen, 2001).

Breschi *et al.* (2000) tries to define technological regimes as a particular combination of key dimensions. They posit four fundamental factors – technological opportunity, appropriability of innovations, cumulativeness of technological advances, and properties of the knowledge base – as being common to specific activities of innovation and production and shared by the population of firms undertaking those activities. Malerba & Orsenigo (1996), Breschi *et al.* (2000) define technological regimes as a particular combination of these four key factors.

Technological opportunities reflect the likelihood of innovating for any given amount of money invested in search. High opportunities provide powerful incentives to the undertaking of innovative activities and denote an economic environment that is not functionally constrained by scarcity. In this case, potential innovators may come up with frequent and important technological innovations.

Appropriability of innovations summarizes the possibilities of protecting innovations from imitation and of reaping profits from innovative activities. High appropriability refers to the existence of ways to successfully protect innovation from imitation. Low appropriability conditions denote an economic environment characterized by a widespread existence of externalities.

Cumulativeness of technical advances is related to the notion that today's knowledge and innovative activities form the base and the building blocks of tomorrow's innovations. An innovation generates a stream of subsequent innovations that are a gradual improvement on the original one, or it may create new knowledge that is used for other innovations in related areas. High levels of cumulativeness are typical of economic environments characterized by continuities in innovative activities and increasing returns.

Lastly, the property of the knowledge base relates to the nature of knowledge underpinning firms' innovative activities. Technological knowledge involves various degrees of specificity, tacitness, complexity and independence and may greatly differ across technologies. Among these, previous literature mainly focuses on specificity. Generic knowledge refers to knowledge of a very broad nature, while specific knowledge refers to knowledge specialized and targeted to specific applications. Generic or focused knowledge is also related to different types of science, i.e. basic sciences generate generic knowledge, while applied sciences generate focused knowledge (Breschi *et al.*, 2001).

Opportunity conditions may depend on the extent to which a sector can draw from the knowledge base, the technological advances of its suppliers and customers, and major scientific advances in universities. And possible appropriability devices are patents, secrecy, lead times, costs and time required for duplication, learning curve effects, superior sales efforts, and differential technical efficiency due to scale economies. Cumulativeness conditions are related to the cognitive nature of the learning process (e.g., learning by doing). Finally, with regard to the properties of the knowledge base, the aspect of the level of specificity reflects that knowledge can be universal and widely applicable, or more specific to particular ways of doing things (Dijk, 1998).

There have appeared some econometric studies on the relationship between the technological regimes and the technological specialization and/or trade specialization in the context of advanced economies Malerba and Orsenigo (1996) try to determine whether a relationship exists between sectoral patterns of innovative activities and international technological specialization. As the dependent variable, they posit the international specialization of a country in terms of revealed technological advantages. The independent variables are the measures used to identify the Schumpeterian patterns of innovation and technological regimes. Breschi *et al.* (2000) take four measures of Schumpeterian patterns of innovation[2] as the dependent variable, and estimate the effects of the technological regime variables on the pattern of innovation. However, they measured the regime variables not by any objective, such as patent, variables but by the responses to survey questions. After categorizing the dependent variable, they estimate a logit model to assess the contribution of the explanatory variables in the probability of observing a Schumpeter Mark I or a Schumpeter Mark II model of innovative activity.

The current study can be an extension of these empirical analysis of the technological regime, but the difference is that we try to link the technological

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2 These are the concentration of innovators, stability of innovators, entry and exit, and the distinction of Schumpeter Mark I or Schumpeter Mark II.

regime with the technological catch-up by the late-comer countries or firms.

2) Technological regime and the Catch-up: Two Main Hypotheses

The implication of technological regimes for catching-up countries differs from that of advanced countries. For example, late-comer economies would suffer in terms of innovation possibility when the technological regime of a sector is featured by high cumulativeness and appropriability because they do not command a good mass of R&D and a sound institutional basis for intellectual property rights (IPR). Mathews (2002) summarizes the characteristics of the latecomer firm. In his discussion, the latecomer is defined as one which meets four conditions. First, in the dimension of industry entry, the latecomer firm is a late entrant to an industry, not by choice but by historical necessity. Second, in the dimension of resources, the latecomer firm is initially resource-poor, e.g. lacking technology and market access. Third, in the dimension of strategic intent, the latecomer firm is focused on catch-up as its primary goal. Finally, for the dimension of competitive position, the latecomer firm has some initial competitive advantages, such as low costs, which it can utilize to leverage a position in the industry of choice.

Therefore, the latecomer firm or catching-up economy is not a "late entrant" in the sense that it did not have the required capability and was not able to enter the markets during the earlier stages even if they wanted to. It starts from the resource-meager position of an isolated firm seeking some connection with the technological and business mainstream. It is through this initial connection that it can leverage its foothold, and through strategic innovation, seek advantages that are intrinsic to its latecomer status and to its earlier experiences in less technologically demanding industries. Likewise, the latecomer firm or catching-up economy is not a start-up like any one of the numerous start-ups that populate Silicon Valley.[3] The latecomer firm or catching-up economy can exploit the same advantages of management of imitation that are available to much better resourced firms, through for example licensing the most recent technologies.

The latecomer firm or catching-up economy formulates a strategy

3 The notion of the latecomer firm excludes "late entrants" through the specification of lack of initial resources, and it excludes "start-ups" through its emphasis on imitation, on creating efficient production systems, and through its dependence on collective institutional resources.

commensurate with its deficiencies and limitations. It looks to the wider world for sources of technology, knowledge and market access. It is in securing access to these resources, for example through low-cost contract manufacturing, that it establishes a foothold in the world's production chains. The latecomer is then able to use this foothold to leverage further resources and turn them into further capabilities, gradually increasing the quality and reliability of production, and the range of functional capabilities (Mathews, 2002).

As asserted by Malerba and Orsenigo (1996), as long as the dimensions of technological regimes are similar across countries, each pattern of innovation ought to be invariant across countries. However, the ability to generate and exploit opportunity is less similar among countries, even among advanced countries. Thus, even if patterns of innovation may be rather invariant across advanced economies, that relation does not hold between advanced economies and catching-up economies. Malerba and Orsenigo have also acknowledged that there may be country-specific patterns of innovation. And it is related to the existence of the major difference between countries in their historical industrial development, in the competence and organization of their firms, and in the architecture and policies of their specific national innovation. They argue that technological imperatives and technology-related factors such as technological regimes play a major role in determining the specific pattern of innovative activities of a technological class across countries, and that within these major constraints identified by technological regimes, country-specific factors introduce differences across countries in the pattern of innovative activities for specific technological class.

There are some works along this line of thought. Lee, Lim and Song (2004) and Lee and Lim (2001) explain the catch-up in 7 industries in Korea in terms of this neo-Schumpeterian notion of technological regime. In their model, technological capability is determined as a function of both technological effort and the existing knowledge base. As determinants of technological effort, they look at the technological regimes of the industries. As determinants of technological effort, Lee and Lim (2001) look at such elements of the technological regimes, as the cumulativeness of technical advances, fluidity (predictability) of the technological trajectory, and the properties of the knowledge base.[4] Using this framework, they argue that when the technological

4 Lee and Lim (2001) identify three different patterns, reviewing the experiences of Korean industries. The first pattern is a path-following catch-up, in which latecomer firms follow the

regime of an industry is featured by higher cumulativeness and a more unpredictable technological trajectory, it is more difficult for catching-up to occur, by large conglomerate style firms in particular.[5]

Although Lee and Lim (2001) show the possibility of relating the phenomenon of catch-up to technological regimes, their work is limited to case studies of selected industries. To test generality of their argument, this paper aim to analyze the link between technological regimes and the technological catch-up by an econometric method using patent data.

Based on the above, let us put forward the first grand hypothesis for research. That is, technological regime also matters for technological catch-up. Having said that there is a close relationship between the different element of each sector's technological regime and the possibility and degree of technological catch-up, we will identify which factors are significant. Out of this first, we can derive many sub-hypotheses that will be discussed later. One of them that we want to emphasize is related to the leapfrogging argument (Perez and Soete 1988) that the time of paradigm shift in technological trajectory often serves as a window of opportunity for late-comers since the disadvantages of the latecomers would not be big during such moment of time as everybody is a beginner. In regression analysis, we will test a variance of this argument by seeing if those sectors with shorter cycle time of technology give better chance for catch-up. Another sub-hypothesis is to look at the opposite side, namely, the role of high appropriability acting as a barrier to entry and/or catch-up.

Now, the second grand hypothesis is related to the issue of organizational selection such that different styles of firms show different degrees of fitness to different environments, which is discussed in Swann and Gill (1993) and Kim and Lee (2003). By a simulation based 'History-friendly model' Kim and Lee

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path taken by forerunners. The second is a stage-skipping catch-up, in which latecomer firms follow the path to an extent but skip some stages and thus save time. The third pattern is a path-creating catch-up; latecomer firms explore their own path of technological development. The writers observes all the three patterns in Korea, such as path-creating catch-up (CDMA mobile phones), path-skipping catch-up (D-RAM and automobiles), and path-following catch-up (consumer electronics, personal computers and machine tools). The first two cases of catch-up may be considered "leapfrogging."(Lee and Lim, 2001)

5 The Korean experiences suggest that a path-following or skipping catch-up is more likely to be relevant to private initiatives in industries where innovations are less frequent or cumulative and the innovation path more predictable, and thus the catching-up target more easily identified. A path-creating catch-up is more likely to occur in public-private collaborations where the involved technology is more fluid and the risk is high with bigger capital requirements. For conglomerates, like Korean chaebols, predictability of the technological trajectory was very important as it enables them to easily fix catch-up targets and concentrate all the resources they can mobilize on the projects (Lee and Lim, 2001).

(2003) analyze how, allowing for entry and exit, different technological regimes carry different consequences for innovation in terms of organizational selection and market structure. And they argue that the shift of industry dominance from small, specialized firms to large diversified firms is more likely to happen when the technological regime of the industry is featured by low cumulativeness and a strong innovation to productivity link. Along this line of thought, we will focus on the difference between two representative countries, Korea and Taiwan, and hypothesize that there will be some difference between these two in terms of the type of the sectors in which each country show more or les catch-up, and that this difference has to do with the fact that one country is dominated by big conglomerate firms and the other by small and medium sized firms. For conglomerates, like Korean chaebols, predictability of the technological trajectory was very important, as it enabled them to easily fix catch-up targets and concentrate all the resources they could mobilize on the projects. In contrast, small or network-based firms, like those in Taiwan, did not feel damaged by fluid environment as they were more flexible than the big but rigid giants in Korea.[6]

3) Regime Variables and the Related Sub-Hypotheses

In this subsection we devise proxy variables for each element constituting the technological regime of the sectors. There are two sets of the variables to serve as explanatory variables in the regressions. The first set of them includes those often discussed in the context of advanced countries by other researchers, and include: technological opportunities, appropriability of innovations, cumulativeness of technical advances, and the property of the knowledge base. In contrast, the other set of them are the ones newly proposed in this study as they would be more relevant in the context of catch-up, and include: accessibility to external knowledge flows, uncertainty or fluidity of the technological trajectory, knowledge gap, a and technological cycle time.

a) Four Old Variables

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[6] It is well-known, for example, that while the Korean chaebols do well in the (scale-intensive) D-RAM segments of the semi-conductor industry, the Taiwanese firms are strong in the (design-intensive) ASIC segment of the industry.

Technological opportunity

Technological opportunity refers to the likelihood of successful innovation for any given amount of money invested for innovation activities. High opportunities provide powerful incentives to the undertaking of innovative activities and denote an economic environment that is not functionally constrained by scarcity (Breschi *et al.*, 2000).

We measure technological opportunity by the annual average growth rate of patents registered in each sector on the application year base. This variable is a good measure of technological opportunity to the extent that the patent registrations of each sector reflect the innovation outcomes of each sector. One might think that the higher the technological opportunity, the more competition is there and hence low possibility of technological catch-up by the latecomers. However, one might also reason that more ambitious latecomer firms also want to jump in these potentially profitable sectors. The regression analysis will find out which reasoning is correct.

Cumulativeness of technological innovation

Cumulativeness refers to the extent to which today's technological innovation depends on past innovation. Innovation generates a stream of subsequent innovations, which are a gradual improvement on the original one, or it creates new knowledge for use in other innovations in related areas. High levels of cumulativeness are typical of economic environments characterized by continuities in innovative activities and increasing returns (Breschi *et al.*, 2000). We measure cumulativeness by the share of total patents in each sector held by persistent innovators in that sector. Persistent innovators are those patent assignees who have continuously registered patents throughout the time period (1980-95).

The higher the cumulativeness, the more difficult it is likely for catching-up countries to achieve catch-up in the direction toward generating competition with incumbent advanced firms.

Appropriability of technological innovation

Appropriability of innovations indicates the possibilities of protecting innovations from imitation and of reaping profits from innovative activities. High appropriability refers to the existence of ways to successfully protect innovation from imitation. Low appropriability conditions denote an economic environment characterized by the widespread existence of externalities (Breschi *et al.*, 2000)

We measure appropriability by the ratio of self-citations received to total citations received. Self-citation is defined as a citing patent assigned by its inventors to the same party as the originating patent. On the one hand, citations to patent that belong to the same assignee represent transfers of knowledge that are mostly internalized within the innovators. On the other hand, citations to patents of others are closer to the pure notion of diffused spillovers (Hall et al, 2001). Therefore, self-citations represent a positive externality that is used by the same innovators. This ratio of self-citation can be computed using patent citation data.

The higher the appropriability of innovation, the more difficult it is for newly entering or catching-up countries to make entry and catch-up. But appropriability of innovations may have less importance if catching-up countries, especially those at lower levels of catch-up, are just trying to emulate pre-existing technologies rather than achieving real innovations.

Originality of the knowledge base

Generic knowledge refers to knowledge of a very broad nature, while specific knowledge refers to knowledge specialized and targeted to specific applications. Generic or focused knowledge may also be related to different types of sciences. Basic sciences generate generic knowledge, by providing broad general understanding that may also affect research in applied sciences. On the contrary, applied sciences are more focused and respond to problems generated by practical experience (Breschi *et al.*, 2000).

Using patent data, we capture and measure this concept as the originality of each patent. Originality can be calculated as suggested in Trajtenberg *et al.* (1997) and Hall *et al.* (2001).

$$\text{ORIGINALITY}_i = 1 - \sum_{k=1}^{N_i} \left(\frac{NCITING_{ik}}{NCITING_i}\right)^2 \text{ where k is technological sector}$$

The higher originality of a patent, the broader is the technological root of the underlying knowledge or research related to the patents. It is probable that synthesis of divergent ideas is characteristic of research that has high originality and hence basic in that sense (Trajtenberg, 1997). If a patent cites previous patents that belong to a narrow set of technologies, the originality score will be low, whereas citing patents from a wide range of fields would render a high score. As a proxy for the nature of technological knowledge, we calculate the mean originality of each sector.

Concerning the nature of technological knowledge, it would be more difficult for latecomer or catching-up countries to acquire generic knowledge that relates knowledge from very broad sources. On the other hand, it is rather easy to gain specific knowledge that is specialized and targeted to specific applications. However, in a newly growing sector such as ICT that involves fusing technology from diverse sources, these factors do not always function against technological catch-up. Aggregation from diverse sources is not a task that the catching-up have to achieve directly, but in most cases, the catching-up acquire and emulate the result of innovation based on aggregation from diverse sources.

b) Four New Variables

Accessibility to external knowledge flows

The existing literature with implicit bias toward the developed economies, tend to focus on the opportunity and nature of knowledge. When considering the situation of catching-up economies, however, external accessibility to international knowledge flows is important. 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 functions for the technological development and catch-up in catching-up economies. Hence, the extent of spillover from advanced countries to catching-up economies in each sector has importance for catch-up.

Accessibility to external knowledge flows, captured as the extent of spillovers from advanced countries to catching-up economies in each sector, is important for catch-up. Spillovers from the core are measured by the proportion of citation, where patent held by non-G7 cite patent held by G7, in total citation.

For catching-up economies, it is important to be connected with a knowledge base abroad, to have access to the international knowledge frontier. A bigger spillover is a larger degree of access to the external knowledge base for catching-up countries. Therefore it is expected that this factor positively affect the possibility of technological catching-up.

Relative technological cycle time (speed of obsolescence of knowledge)

One important attribute of knowledge is the fact that it gets obsolete over time, and in this respect knowledge differ. Some knowledge get obsolete quickly while others not. We can expect that the speed of obsolescence affects the chances of catch-up. If the life expectancy of knowledge is long, acquiring technology from abroad accompanies a heavy dependence upon the forerunning innovators fully appropriating the technology over a long time. However, if it is short-lived, catching-up countries can acquire technology at a time that is similar to advanced countries, enabling them to specialize in an area according to their technological capability at that time. This factor can be expressed as the technological cycle time.[7]

The relative technological cycle time is measured by the ratio of technological cycle time of patents in a sector to that of all patents. A value greater than 1 represents a longer cycle time and thus lower speed of change in the knowledge base of the sector; a value less than 1 represents a high speed. Technological cycle time is measured by the time span between the predecessor and the successor, and is calculated as the time difference between the application year of the citing patent and that of the cited patents.

The long cycle time means greater importance of old knowledge and hence more need to study old knowledge from the late-comers' point of view. But, when knowledge in the field changes quickly, the disadvantages for the latecomer might be smaller. Thus, we hypothesize that the shorter cycle time of a sector is, the higher possibility of catch-up. Actually, this reasoning is consistent with the leapfrogging hypothesis (Perez and Soete 1988) which asserts that during the time of paradigm shift, the latecomers have higher chances to catch-up with the forerunners because everybody is now a beginner in the emerging industries.

Initial stock of accumulative knowledge

Previous literature focuses on the cumulativeness of technology and the possibility of appropriability of technology innovation. But when considering

[7] It is possible to distinguish cumulativeness of technological advance from technological cycle time, or speed in the change of knowledge. Although both comprise cumulativeness in a broad sense, the first represents cumulativeness of technology at the organization dimension, while the latter represents the inverse of cumulativeness of technology itself.

the situation of catching-up economies, the knowledge gap with advanced countries for every technological sector must also be addressed. The larger the gap, the more difficult it is to catch-up, and this acts against rigorous technological effort. In this light, we want to introduce the variable of initial stock of accumulative knowledge as one explanatory variable as it also represents the amount of knowledge in each sector that catching-up economies have to master to conduct innovation in that sector. This might act as a barrier for catch-up and functions as the environment that affects the decision of which sector is selected and targeted for catch-up. However, on the other hand, there is also possibility for accumulative knowledge to function as a pool of knowledge to be utilized by the catching-up firms and countries.

We measure this variable as total number of the US patents in each sector normalized by the total number of the US patents in all sectors.

Fluidity (uncertainty) of technological trajectory

The way technological development or innovation occurs affects the selection decision of catching-up countries. It is because the position of acquiring and imitating technology from external sources is prone to be passive and wants to expect the trajectory of technology relatively correctly, although it differs according to the nature of dominant organization. This element can be described as the uncertainty or fluidity of technological trajectory.

For effective catch-up in catching-up economies, it is inevitable that limited resources, especially R&D resources, be focused on a few select sectors and a catching-up strategy created on a national dimension. Thus, in order to be chosen for strategic selection, it would be better if the technological trajectory is to be predictable.

We measure predictability (or fluidity) of technological trajectory of a sector as the coefficient of variation of the annual growth rate of patents in each sector. The coefficient of variation is the standard deviation divided by the mean. It is hypothesized that under high fluidity (uncertainty) environment, it is more difficult for big conglomerate firms to devise a stable catch-up strategy focusing limited resources on targeted future development items with certainty. In contrast, those SMEs in another catch-up country like Taiwan would have feel such fluid environment not to much disadvantageous for them as they tend to be more flexible compared to Korean Chaebols. In other words, this variable is to serve to test the organizational selection hypothesis that the firms with different organizational characteristics would show different degree of fitness to the diverse environment.

3. The Data and the Structure of the Regressions

1) Data

Innovation is a complex and heterogeneous process that is becoming increasingly important in economic growth and economic life. In order to understand the innovation process, detailed sources of information are needed. Traditionally R&D-related data, comprised of expenditure, number of personnel, number of research institutes etc, were used as the only source of information.

Recently patent data and innovation surveys have emerged as two alternative ways to acquire information on innovative activities, especially of firms. A wide variety of innovative activities are carried out by firms, among which the introduction of product and process innovation and patenting are two specific activities that can be documented by innovation surveys and patent data.

Between these two sources, patent data provide unique information on the detailed classification of innovators, technology and time. Patent data have advantages and disadvantages as a technological indicator (Archibugi and Pianta, 1996).[8] Their advantages are as follows: First, they are a direct outcome of the inventive process, and more specifically of those inventions which are expected to have a commercial impact. They are a particularly appropriate indicator for capturing the proprietary and competitive dimension of technological change. Second, because obtaining patent protection is time-consuming and costly, it is likely that applications are filed for those inventions which, on average, are expected to provide benefits that outweigh these costs. Third, patents are broken down by technical fields and thus provide information not only on the rate of inventive activity, but also on its direction. Fourth, patent statistics are available in large numbers and for a very long time series.

However, patent counts from different patent offices are not always comparable to each other because of different patent breadths, patenting costs, approval requirements and enforcement rules for patenting in different countries. A common remedy is to use patent data from a single patent granting

6 Also can refer to Griliches (1990), Basberg (1987), Pavitt (1998), OECD (1994), Hall, Jaffe, Trajtenberg (2001) etc.

country like U.S. to standardize the unit of innovation, making cross-country comparisons possible. Since the U.S. is the largest and the most technologically advanced market in the world, any sufficiently big invention being patented anywhere with a global market in mind is likely to be patented in the U.S. as well (Mahmood et al, 2003).

We aim to analyze the economic phenomenon of technological catch-up, using these patent data. We use the USPTO patent data. Specifically we use the NBER patent database.[9] This patent database is comprised of patents registered from 1963 to 1999. It also has patent citation data made from 1975 to 1999. The data set extends from January 1, 1963 through December 30, 1999 (37 years), and includes all utility patents granted during that period, totaling 2,923,922 patents.[10] And the citations data includes all citations made by patents granted in 1975-1999, totaling 16,522,438 citations.

The information of this database is as follows. (1) Patent number, (2) Grant year, (3) Grant date (4) Application year (starting in 1967) (5) Country of first inventor (6) State of first inventor (if US), (7) Assignee identifier, if the patent was assigned (starting in 1969), (8) Assignee type (i.e., individual, corporate, or government; foreign or domestic), (9) Main U.S. patent class, (10) Number of claims (starting in 1975). And patent citation data contains citing patent number and cited patent number.

The data contains the address of residence of each inventor. Country is identified by the address. For patents involving multiple inventors, the country is identified by the address of first inventor. Although this sort of identification is misleading for some cases such as invention by American employee of Korean firms, we assume that this problem is minor.

Similarly to the existing literature, we had no choice but to confine technological innovation reflected on patents data, despite some intrinsic limits of patent data as output data of innovations.[11] In consideration of the nature of

8 See the NBER site at: http://www.nber.org/patents/. The detailed contents and characteristics can be found in Hall et al (2001) and Jaffe et al (2002).
9 A utility patent granted is more strict terms in US terms.

[11] Thus, we are not free from the following disadvantages of using patent data in innovation studies. First, not all inventions are technically patentable. Second, not all inventions are patented. Third, firms have a different propensity to patent in their domestic market and in foreign countries, which largely depends on their expectations for exploiting their inventions commercially. Lastly, although there are international patent agreements among most industrial countries, each national patent office has its own institutional characteristics, which affect the costs, length and effectiveness of the protection accorded. In turn, this affects the interest of

patent citation data, the so-called truncation problem, and the actual situation of catching-up countries, especially of Korea and Taiwan, we confine our analysis to periods of 1980-1995.

2) Structure of the Regression Models

In this section, we build an empirical model analyzing the technological catch-up phenomenon of catching-up economies. Specifically, we aim to examine the phenomenon in terms of technological regimes. We devise regression models to find the characteristics of the industrial sectors in which catching-up tend to occur, and develop proxy variables to represent various aspects of the technological regimes by using patent data and patent citation data.

Technological catch-up is defined as the faster increase of technological capability than others, and technological capabilities of a country in a specific sector is here measured by the share of that country in the total patents in that sector. Then, our investigation of the catch-up process is done in terms of the following three dimensions:

First, we note that not in every sector technological catch-up occurs. In other words, there are some sectors in which catching-up economies do not register any patents or their amount of registered patents never increases. Thus, we first examines what determines the probability of the occurrence of technological catch-up after defining the 'occurrence' as the increase of the share of a country from zero to positive or from a positive number to a bigger number. The reason we pay attention to this occurrence is that we have observed that one important aspect of catch-up is having been able to register in more and more diverse sectors, namely increasing diversity of their technological capabilities. Thus, our specific question in which sectors featured by which technological regimes there is more possibility of the occurrence of technological catch-up. For this question, the specification of the regression model is as follows:

Probability of technological catch-up = F (technological regimes)

For this regression specification, we estimate a probit model appropriate for

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inventors in applying for patent protection.

a qualitative binary dependent variable and find out the contributions of different elements of the technological regimes to the probability of technological catch-up.

Second, we pick up only those sectors where technological catch-up occurs, and then ask what determines the degree of catch-up. For this question, the regression specification is as follows:

Degree of technological catch-up in each sector = F (technological regimes)

Finally, the different levels of possibility of, and degree of, catch-up determine the level of technological capability of economies in each sector. In other words, in some sectors late-comer economies will achieve higher technological capabilities (namely higher share of their patents in sector) owing to the factor the sector tend to give higher possibility of catch-up and also higher degree of catch-up, while in other sectors their achievement would be lower because those sectors give them some intrinsic difficulties associated with the technological regimes of the sectors. For this question, the regression specification is as follows.

Technological Capability = F (technological regimes)

Different elements of the technological regimes are represented by the factors of technological regimes suggested by Breschi *et al.* (2001) and also other elements we find appropriate for catching-up economies. In order to test this hypothesis, we will measure each element of technological regimes and use econometric analysis to determine which elements have a close relationship with the building of technological capability and hence the degree of catch-up. We posit 1980-1995 as the appropriate time period, in consideration of the characteristics of the database and the history of innovation in catching-up economies.

4. The Regression results

1) Determinants of the probability and the Degree of technological catch-up

First, we conduct a probit analysis of the probability of technological catch-up in terms of technological regimes. Probit analysis is used for analyzing a qualitative binary dependent variable, presupposing the normal distribution of the error term. Here, the dependent variable measures whether or not there is an occurrence of technological catch-up. The occurrence of technological catch-up is defined as a positive change between the patent share of a country at the beginning period and the patent share of that country at the end period. If there is an occurrence or a positive change, the value of the dependent variable is set to 1. Otherwise, it is set to 0.

Based on this criterion, in Korea, there are 292 sectors showing technological catch-up and 84 sectors that do not. Meanwhile, in Taiwan, there are 320 sectors showing technological catch-up and 56 sectors that do not.

Table 1 shows the results of regression for Korea, Taiwan and these two countries as a group (called catching-up economies).

First, we note that there are two factors of the technological regimes that show a consistent pattern across three regressions. They are initial stock of cumulative knowledge (INITIAL) and technological cycle time (CYCLE TIME). It implies that in a sector featured by shorter technological cycle time, catch-up is less likely to happen as expected, that the more initial stock of knowledge in sector the more likely is the catch-up.

Second, we note that there are three variables that differentiate Korea from Taiwan. It is shown that only Korean firms are adversely affected by higher opportunity and higher fluidity. The negative impact of the fluidity of technological trajectory is what we have hypothesized in terms of the organizational selection argument. In other words, as they are bigger and possibly less flexible, they show less fitness in the environment featured by higher fluidity. Meanwhile, it is also shown that Taiwan has achieved catch-up in sectors with higher appropriability.

Table 1: Possibility (occurrence) of technological catch-up and technological regimes

variables	Catch-up countries	Korea	Taiwan
Constant	1.83431 (0.575623)***	3.13529 (0.904989)***	1.0748 (0.837422)
OPPOR	-0.39358 (0.37638)	-1.3716 (0.605172)**	0.3456 (0.57909)
CUMUL	-0.23398	0.36081	-0.867

	(0.682674)	(1.075143)	(0.948127)
APPRO	0.76828 (0.651915)	-0.6571 (0.962748)	2.8499 (0.981924)***
ORIGINALITY	1.23062 (0.720995)*	1.03393 (1.072662)	1.3809 (1.042298)
FLUID	-0.00419 0.00259	-0.0293 (0.007735)***	0.0022 (0.004004)
INITIAL	3.69922 (0.607641)***	4.55234 (1.016438)***	4.1749 (0.816898)***
CYCLE TIME	-1.81738 (0.456988)***	-2.3259 (0.717174)***	-1.71 (0.638727)***
SPILLOVER	-3.14399 (2.275321)	-6.4529 (3.334414)*	1.9368 (3.322045)
TW	0.31475 (0.120048)***		
Log likelihood LR statistic McFadden R-squared Number of observations	-288.816 145.223 0.2009 752	-135.02 129.409 0.32397 376	-133.4 49.773 0.1573 376

Note: The method of Newton-Raphson is used

Note: ***, ** represent significance at 1%, at 5%, respectively

Note: Numbers in parenthesis indicate standard error.

Note: TW represents dummy for Taiwan.

Based on the results of this regression, we can conjecture that fast change in technological knowledge permits technological niches and room for catching-up, thus promoting the possibility of technological catch-up. Also, positive sign of the variable of initial stock of accumulative knowledge imply that pre-accumulative knowledge functions as a pool to be utilized by the catching-up countries and contribute to the widening of the scope of technological innovation in catching-up countries.

It is also shown that technological opportunity of innovation, as well as the variable representing the fluidity of technological development, negatively affects the possibility of technological catch-up only in Korea. This is consistent with the argument of Lee and Lim (2001). They argue that, when the technological regime of an industry features higher cumulativeness and a more unpredictable technological trajectory, it is more difficult for catching-up to occur, by large conglomerate style firms in particular. Given that Korean Chaebols tend to be less flexible and pursue more independent R&D strategy without being deeply dependent upon the MNCs from the advanced countries, compared to Taiwanese SMEs., this is because a higher frequency of innovation in a given time and a very fluid technology trajectory make it hard to make sufficient R&D effort and expenditure and fix the R&D target, as indicated in Lee and Lim (2001).

Meanwhile, in the case of Taiwan, it is shown that higher appropriability positively affects the possibility of technological catch-up. Theoretically, it is conjectured that high appropriability hinders imitation and emulation by other innovators, thus functioning against the possibility of technological catch-up. But the result of this regression does not like this theoretical direction. On of possible explanation is that Taiwanese firms are characterized as small firms with a minimum R&D base (Choung, 1998), thus tend to try to specialize in a narrow area and pursue cooperative R&D instead, compared to diversified large firms. Given this characteristics, much more reaping of previous innovations make it easy to achieve a technological catch-up.

Next, we pick up only those sectors what have shown the occurrence of catch-up and analyze what determines the degree of technological catch-up in these sectors.[12] We also focus on the difference between two typical catching-up countries, Korea and Taiwan. In regressions, the dependent variable, the degree of technological catch-up, is measured by the change in the share of each sector in the period of 1980-1995. That is, it is measured by the extent of increase in the Korean and Taiwanese share of each sector.

Table 2 shows the selected sectors that rank highest in terms of technological catch-up. While Korea mainly shows a high degree of technological catch-up in the electric and electronics sector and the computer and communication sector, Taiwan mainly shows that in the mechanical sector.

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12 As previously asserted by Malerba and Orsenigo (1996), we cannot say much about the direction of causation between the sectoral level of catch-up and the factor of technological regimes. Rather, we interpret the result of the regression simply in evidence of the existence or absence of correlation between the variables that represent them.

Table 2: Selected technological sectors that show a high degree of catch-up in catching-up countries

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

Now, table 3 shows the results of the estimation for Korea, Taiwan, and the two countries as a group. Now there is not any variable that shows the same significant signs in all the three regressions. This implies that when we confine to only sector showing occurrence of catch-up, differential characteristics of each economy is dominant or pivotal.

Therefore, in these regressions to determine the speed of catch-up in those sectors where catch-up tend to occur, we find more difference between Korea and Taiwan. For Korea, the variable representing cumulativeness (persistence) of technological advancement is positively associated with the degree of technological catch-up, while the variables representing initial stock of technological knowledge and appropriability of previous innovation are negatively associated with it. For Taiwan, while the variable representing the spillover of technological knowledge from advanced countries to non-advanced countries and the variable of appropriability are positively associated with the degree of technological catch-up, the variables representing technological cycle time and cumulativeness (persistence) are negatively associated with it.

In regression which put both countries together as a group, positive impact of appropriability (from Taiwan model) and easiness of spillover (from the Taiwan model) are confirmed. These results come from the fact that Taiwan's influence dominates that of Korea, as shown by the number of sector making technological catch-up.

Table 3: Degree of technological catch-up and technological regimes

variables	Catch-up countries	Korea	Taiwan
Constant	1.9765 (3.582258)	3.34423 (3.593969)	4.9562 (4.590533)
OPPOR	11.8521 (8.586519)	2.49591 (3.284392)	12.143 (9.863452)
CUMUL	-2.61099 (2.022864)	7.1916 (2.623982)***	-11.94 (2.539309)***
APPRO	15.3622 (4.667687)***	-7.6807 (3.105953)**	31.064 (7.119972)***
ORIGINALITY	-1.33811 (2.63988)	1.89145 (2.0374)	-2.747 (4.345425)
FLUID	-0.00045 (0.007021)	-0.0058 (0.006535)	-0.004 (0.007714)
INITIAL	-1.01118 (0.768763)	-2.2622 (0.686944)***	-0.209 (0.996944)
CYCLE TIME	-3.96036 (2.532389)	-0.7683 (2.916353)	-7.981 (3.398828)**
SPILLOVER	51.0541 (17.87132)***	25.7124 (16.0415)	68.296 (26.18167)***
TW	1.61673 (0.420909)***		

R-squared	0.17227	0.14299	0.3085
Adjusted R-squared	0.15989	0.11877	0.2907
F-statistic	13.921	5.90233	17.346
Number of observations	612	292	320

Note: White Heteroskedasticity-Consistent Standard Errors & Covariance

Note: ***, **, * represent significance at 1%, 5% and 10%, respectively

Note: TW represents dummy for Taiwan

Note: Numbers in parenthesis indicate standard error.

As for the degree of technological catch-up, we have found that the difference between Korea and Taiwan is striking even in the same variables. For Korea, innovative firms tend to make a catch-up in sector featured by high cumulativeness (persistence) and low appropriability, while Taiwan shows the opposite. Following explanation can be made.

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 sector of high cumulativeness (persistence), large innovative firms tend to dominate the technology and market. But, lower cumulativeness (persistence) is related to the opposite possibility. And as previously discussed, appropriability positively works for specialist small firms, because, it make it easy to focus on narrow area with relatively few R&D resource. Meanwhile large conglomerates tend to diversify in broad area rather than continuously focus on narrow area of technology, thus appropriability does not work positively.

The Korean Chaebols is shown to be not sensitive to the availability of access to external knowledge as they rather tend to build on their own past R&D achievement as shown by the positive sign of cumulativeness variable, although they are much dependent upon advanced firms for essential technology. Thus, for Korean Chaebols, cumulativeness does not hinder effective technological catch-up as theoretically expected, or as in advanced countries.[13] It is rather contingent on the method or strategy of technological learning adopted by catching-up countries, as indicated. However, for these firms pursuing more

[13] In technological regimes where technological advances take place in a cumulative way, innovative entrants find themselves at a major disadvantages with respect to incumbents (Winter, 1984, Breschi *et al.*, 2000)

independent firms, the bigger stock of cumulative knowledge act as a barrier to a more speedy catch-up, as shown by the negative sign of the initial stock variable for Korea. This variable is not significant for Taiwan because they tend to employ more dependent strategy to the forerunners.

In the meanwhile, shorter technological cycle time and higher access to the international knowledge pool tend to enhance the degree of technological catch-up in Taiwan, compared to Korea. As previously discussed, small firms more easily find technological niches that are appropriate for their firm size and have an advantage when there is an easy access to the external knowledge. In this case, the possibility of reaching external technology promptly, i.e. whether or not they can import and acquire practically the new technology, is very important.

We now summarize the results of the estimation by putting together the two aspects of technological catch-up. First we have found that there are no common elements in terms of both possibility and degree of catch-up even though some common elements for specific country. There are some difference between possibility and degree of catch-up. For possibility of catch-up, elements such as initial stock and technological cycle time hold for catch-up countries as a whole, while there are elements only differential for Korea and Taiwan for degree of catch-up. From this, it is certain that the elements and its way to affect are different owing to the aspect of technological catch-up, that is, whether it is in case of possibility or degree of catch-up.

Second, in specific, we have found that while both variables of initial knowledge stock and technological cycle time affect significantly the possibility of technological catch-up in both countries, they do not affect the degree of catch-up significantly. This is interesting, important and somewhat expected. Our reason is that catch-up is more likely to happen in those sectors where the disadvantage of late-comer is small owing to short cycle time, but this shortness of cycle time does not affect the speed of catch-up itself (as in case of Korea). In other word, catch-up could happen, and it can be slow or fast catch-up, depending upon other factors. Similarly our reasoning is that catch-up is likely to happen in those sectors where more patents have been registered in the past, but this fact does not give them any help in shortening the time of catch-up. In other word, more stock of accumulated knowledge seems to mean lower barrier of entry but it might rather affect adversely (as in the case of Korea) the actual speed of catch-up once entry occurred in that sectors unless you have setup stable access to the continuously increasing stock of knowledge, probably as in the case of Taiwan.

2) Different Levels of Technological Capabilities and its Determinants

So far we have discussed which elements of the technological regimes determine the probability and degree of catch-up. Now we focus on the absolute levels of technological capabilities realized as a result of sectoral differences in the occurrence and degree of catch-up. In other words, we posit the following relationship.

Levels of Technological Capabilities achieved by catch-up economies in each sector = F (occurrence of catch-up, degree of catch-up).

This relationship suggests that in some sectors catch-up has never happened and thus the levels of technological capabilities achieved by the catch-up economies are so low. Difference also exists among those sectors that have some degree of catch-up because some sectors boast faster or lower rate of catch-up.

Table 4 shows the results of the regression results to find the determinants of the sectoral levels of technological catch-ups.

Table 4: Technological capability and technological regimes

Variables	Advanced countries	Catch-up countries	Korea	Taiwan
Constant	-0.007 (1.3912)	2.255 (1.299051)*	3.267 (1.164835)***	2.719 (2.028447)
OPPOR	0.401 (1.630434)	1.662 (2.48759)	-1.005 (0.330121)***	4.328 (4.181271)
CUMUL	-3.299 (1.329671)**	-2.071 (0.961164)**	2.993 (1.064222)***	-7.135 (1.308526)***
APPRO	-1.990 (1.924043)	10.583 (2.587189)***	-2.007 (1.022403)*	23.173 (4.342863)***
ORIGINALITY	-2.865 (1.659448)*	-0.037 (1.259217)	0.919 (0.826872)	-0.993 (2.223473)
FLUID	0.003 (0.005922)	-0.004 (0.002909)	-0.004 (0.001461)**	-0.003 (0.00339)
INITIAL	0.635 (0.395755)	-0.217 (0.34321)	-0.823 (0.268223)***	0.390 (0.555905)
CYCLE TIME	8.193 (1.077178)***	-3.529 (1.034245)***	-1.759 (0.952672)*	-5.299 (1.618113)***
SPILLOVER	-5.065 (7.119563)	17.011 (7.353109)**	4.100 (4.456861)	29.923 (12.10595)**
CA	-0.997 (0.350266)***			
DE	12.713 (0.52838)***			
FR	0.248 (0.324906)			
IT	-4.023 (0.265645)***			
TW		1.476 (0.245141)***		
R-squared	0.52181	0.1379	0.1413	0.30647
Adjusted R-squared	0.51873	0.12744	0.1226	0.29135
F-statistic	169.773	13.1873	7.5494	20.2716

Number of observations	1880	752	376	376

Note: White Heteroskedasticity -Consistent Standard Errors & Covariance

Note: ***, **, * represent significance at 1%, 5%, and 10 % respectively

Note: FR, DE, IT, CA and TW represent dummy for France, Germany, Italy, Canada and Taiwan respectively

Note: Numbers in parenthesis indicate standard error.

First of all, as expected, the result is something like a synthesis of the results in the preceding section about the determinants of the probability and degree of catch-up. For example the column showing the significant variables in the regression for the two catch-up countries as a group is pretty much the same as the summation of the two columns showing the results the probability and degree of catch-up, except the variable of cumulativeness and the variable of initial stock of knowledge. In other words, those variables having significant impacts on the technological capabilities are cumulativeness (-), appropriability (+), technological cycle time (-), and spillover (+). Among these, those sectors having the same signs in regressions for both Korea and Taiwan include only one; technological cycle time.

Short cycle time or faster change in technological knowledge permits technological niches and room to emerge for catching-up economies, thus promoting the building of technological capability by the late comers. This point is similar to the leapfrogging argument by Perez and Soete (1988) and Freeman and Soete (1997), who argue that the new technological paradigm permits leapfrogging by developing countries.

Thus, we can say, regardless of whether the firms are of the conglomerate type or SME types, catch-up economies would achieve higher levels of technological capabilities in such sectors as featured by short cycle time of technology. Interestingly, as we run the same regressions, we find that the cycle time has a significantly positive sign, which means that the advanced countries do well in those sectors with longer cycle time, as expected. Also we find that it is cumulativeness that acts as a hindrance to enhanced technological capabilities, for advanced countries.

Here, in the regressions, advanced countries include the G7 excluding the U.S. and Japan. Japan is excluded due to its peculiarity; it is usually considered as having an abnormally high propensity to patent in the USPTO. Hence it is excluded for a conservative analysis. Thus in this study, Germany, France, U.K., Canada, and Italy comprise the advanced countries.

In the regression results presented in table 4, we again notice the consistent difference between Korea and Taiwan. Actually, the difference shown in the preceding analysis of the probability and degree of catch-up is here repeated in a quite consistent and expected pattern, which confirms our reasoning. For the Korean case, opportunity, fluidity, and the initial knowledge stock are shown to be significant and of the expected sign. For the Taiwan case, spillover is shown to be significant and of the expected sign. And further two countries show opposite signs in terms of cumulativeness (persistence) and appropriability of previous innovation.

As asserted in Swann and Gill (1993), Kim and Lee (2003) and Lee and Lim (2001), 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. It is well-known that the Korean economy and its innovation activities are spear-headed by large diversified business groups, whereas Taiwanese economic activities are dominated by relatively smaller but specialized firms. Thus, the negative sign of fluidity in the Korean case is consistent with the reasoning that the more unpredictable the technological change or trajectory, the lower the market share of large diversified firms and the lower the market concentration.

Our findings are consistent with the following characterization of the firms in Korea and Taiwan. The Korean firms, dominated by so-called Chaebols especially in patent registrations, are characterized as less flexible and large diversified conglomerates and pursing more independent R&D and learning strategies. Taiwanese firms are characterized as more flexible and network-based and pursing 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 forerunning firms.

In terms of different strategy of different organizations, Korean firms has made a technological catch-up in sectors of low appropriability and high cumulative (persistence) dominated by advanced firms, given the characteristics of large diversified conglomerates and pursuing relatively independent strategy. Meanwhile, Taiwanese firms achieved technological catch-up in sectors of high appropriability and low cumulativeness (persistence) easy to avoid the direct competition with advanced firms, given the characteristics of small specialized firms and relatively cooperative strategy.

5. Summary and Concluding remarks

Since first emphasized by Nelson and Winter, the 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, 1997). Recently, Lee and Lim (2001) and Lee, Lim and Song (2004) try to link the technological catch-up by the late-comer firms with the technological regimes in their case studies of seven industries in Korea; this study focused on the cumulativeness of technical advance and predictability of the technological trajectory as important components of the technological regime relevant for catching-up.

This paper extends and generalizes the preceding research by econometric analysis of the relationship between the technological regime and the possibility and conditions of technological catch-up, using U.S. patent data. That is, the notion of technological regimes appropriate for catching-up economies should be extended to comprise accessibility to external knowledge flows, uncertainty or fluidity of technological trajectory, initial stock of technological knowledge, technological cycle time in addition to technological opportunities, appropriability of innovations, cumulativeness of technical advances, and the property of knowledge base.

Using patent data and patent citation data, we develop a quantitative expression of technological regimes and investigate in which sectors technological catch-up tends to, or not to, occur and what affects the degree of technological catch-up. With this method, we aim to analyze the determinants of several aspects of technological catch-up in Korea and Taiwan, which are regarded as typical catching-up economies.

First, this study has tried to analyze the phenomenon of technological catch-up. In order to analyze in detail, we distinguish that phenomenon into the possibility of technological catch-up and the degree of technological catch-up among the sectors achieving technological catch-up. Second, this study has tried to explain the sectoral differences in the levels of technological capability in catching-up economies as combined effects of the occurrence of catch-up and the degree of catch-up, and also tried to compare the results with that with advanced countries. All the results of regression are summarized in table 5.

Table 5: The signs of coefficients in estimation of determinants of technological capability and catch-up in Korea and Taiwan

Variable	Technological capability				Possibility(occurrence) of technological catch-up			Degree of technological catch-up		
	Advanced countries.	Catch-up countries	Korea	Taiwan	Catch-up countries	Korea	Taiwan	Catch-up countries	Korea	Taiwan
OPPOR			(-)***			(-)**				
CUMUL	(-)**	(-)**	(+)***	(-)***					(+)***	(-)***
APPRO		(+)***	(-)**	(+)***			(+)***	(+)***	(-)**	(+)***
ORIGINALITY										
FLUID			(-)**			(-)***				
INITIAL			(-)***		(+)***	(+)***	(+)***		(-)***	
CYCLE TIME	(+)***	(-)***	(-)**	(-)***	(-)***	(-)***	(-)***			(-)**
SPILLOVER		(+)**		(+)**		(-)**		(+)***		(+)***

Note: Only the signs of coefficients having significance are shown.

Note: ***, ** represent significance at1%, at 5%, respectively

This study has confirmed the basic hypothesis that different elements of technological regimes have different implications for the technological catch-up and hence for building technological capability. One of the more robust and specific findings is that longer cycle time of technology of a sector implies a lower possibility and degree of technological catch-up and hence lower level of technological capability attained by catching-up economies. To put it simply, this finding imply the window of opportunity opened up by the rapid technological change as asserted by the leapfrogging argument.

The study also confirms the organizational selection hypothesis such that the firms of different organizations and strategies show divergent degree of fitness in the different environment or technological regime. We find that the Korean firms find themselves less fitted in such environment featured by high fluidity and rapid increase of knowledge, and they made a catch-up in sectors of low appropriability and high cumulative (persistence) dominated by advanced firms whereas the Taiwanese firms less fitted, by low spillover and achieved technological catch-up in sectors of high appropriability and low cumulativeness (persistence). Our findings are consistent with the following characterization of the firms in Korea and Taiwan. The Korean firms, dominated by so-called Chaebols especially in patent registrations, are characterized as less flexible and large diversified conglomerates and pursing more independent R&D and learning strategies. Taiwanese firms are characterized as more flexible and network-based, specialized and pursing more cooperative R&D and learning strategies.

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