경제학박사학위논문

Patterns of Catch-up in Technologies and Markets:

Findings from the Four Cases Using Patent Data

기술과 시장에서 추격의 패턴

-4 가지 사례를 통한 특허 데이터 분석-

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서울대학교 대학원

경제학부 경제학전공

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Patterns of Catch-up in Technologies and Markets: Findings from the Four Cases Using Patent Data

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Abstract

This study focuses on two questions: how are latecomer firms in developing countries with low quality products and no brand recognition able to catch up with industry forerunners in developed countries with advantages in every aspect and do those firms follow any particular pattern achieving their success?

Several previous studies have explored the process by which particular companies were able to catch up with industry forerunners, but thus far have provided only fragmentary explanations. As such we have divided our primary research question of what process latecomers follow in catching up with industry forerunners into the following four research questions.

1) Are latecomers able to catch up with forerunners in the market without technological capabilities?

2) Do latecomers utilize technologies that are similar to or distinct from those employed by forerunners?

3) Is it necessary for latecomers to invest in cutting-edge or more recent technologies in order to catch-up?

4) Do science-based technologies increase over time during the catch-up process?

In seeking answers to the aforementioned research questions, we conducted an in-depth analysis of the catch-up phenomenon from the technological perspective primarily by using patent data, which has become more widely available in recent times, and reviewing existing catch-up theories.

We reviewed several cases, in which latecomers in developing countries did catch-up with the leaders in developed countries in different sectors, in order to examine whether a set of patterns exits that are generally followed by latecomers in the catch-up process. In particular, we selected

the case of Huawei and Ericsson in the telecommunications equipment sector, Samsung Electronics and Sony in the electronics sector, Hyundai Motors and Mitsubishi Motors in the automobile manufacturing sector, and POSCO and Nippon Steel Corporation in the steel production sector. Huawei, Samsung, Hyundai Motors and POSCO are all large companies from developing countries that successfully caught up with forerunners in their respective sectors. An in-depth analysis of each pair of companies was conducted using patent data and other technological indices to find the similarities and differences in the technological catch-up process followed by each latecomer. A review of the existing literature and examination of outcomes revealed possible common patterns in the technological catch-up processes followed in the different sectors studied.

First, latecomer's technological catch-up tends to precede a catch-up in the market. This reflects the fact that accumulated technological capabilities are the foundation of the catch-up process and a necessary condition for sustainable; rather than temporary; dominance over a longer period of time.

Second, latecomers tend to catch-up by using technologies that differ from those employed by incumbents. This was determined, considering the level of technological dependence between two firms, self-citation ratio and the number of received citations of patents.

Third, whether a latecomer can succeed in catching up with the forerunner by relying on more recent technologies depends on the technological nature of the sector, especially the typical length of the sector's technology cycle. This reflects the fact that during the catching-up process, latecomers depend on more recent technologies in the sector with short technological cycle and frequent generation change, while latecomers in the sector with less frequent technological generation change gradually tend to improve the existing technologies in a different way from forerunners rather than investing in up-to-date technologies,

which can be verified by the measure of backward citation lag.

Fourth, whether a latecomer's patent has a higher proportion of science-based citations tends to depend on the nature of the sector's knowledge base. Whereas the knowledge base of the IT sector depends on radical innovation and explicit knowledge, the knowledge base of the automobile manufacturing sector depends on gradual innovation based on experience and experimentation as well as tacit knowledge.

This study conducted an in-depth analysis and examination of the aforementioned specific research questions through patent data analysis and drew the following conclusions with regard to the catch-up process: A accumulated technological capacity is the base for the catch-up of latecomer firms with the forerunners, the latecomer catch-up with incumbents based on different technologies from the incumbents, latecomers in sectors with a short technological cycle try to catch up with the leaders by depending up-to-date technologies, and the share of basic science in their patents of latecomers tends to gradually increase in sectors with little tacit knowledge.

Lastly, this paper can provide directions for firms as to what conditions are needed for to be able to catch up with forerunners by making explicit the existence of several possible patterns of catch-up within the sector from the technological perspective through the patent analysis data. In addition, this study provides practical and useful implications for both incumbents and latecomers in establishing their technological strategies in general and their patent strategies in particular.

Key words: Patterns of catch-up, Technological catch-up, Catch-up in the market, Patents, Level of technological dependence, Self-citation ratio, The number of received citations, Backward citation lag, Science-base, Knowledge base, Sector

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Chapter one
Introduction

Repeated leadership changes from one company to another, whether within a nation or a specific sector of the nation, have come to be perceived as a natural phenomenon in today's world. Many intrigued scholars from the field of economics and business, set out early on to understand the dynamics of this phenomenon and produced research that provided, a fairly reliable but limited explanation of such industry ups and downs. Missing from these earlier works, however, was insight into the catch-up of latecomer countries- a phenomenon where advanced nations are caught up and overtaken in certain fields by late-comers like Korea and Taiwan. Nor were such studies accompanied by an understanding of the forces driving the disproportionate occurrence of latecomer catch-up in particular sectors. To address the limitations of earlier works, a recent stream of research has taken up the challenge of understanding why catch-up is more likely to occur in certain sectors than in others as well as its underlying reasons. From the Neo-Schumpeterian perspective -under which technological change is assumed to be the fundamental force behind economic transformation- several studies have looked into the catch-up dynamics at national, sectoral and firm levels and led to the formulation of the "catch-up theory".

A number of significant findings have arisen from these technological catch-up studies. At the national level, a quantitative analysis of industrial catch-up of nations by Park and Lee (2006) examined the technological catch-up experiences of Korea and Taiwan,two shining examples of successful catch-up economies, concluding that these fast followers thrive in fields where technology cycles are frequent or short. An analysis of technological catch-up at the sector-level by Jung and Lee (2012) presented comparative findings of Korea vs. Japan and used productivity factors to discover four catch-up determinants –technology tacitness, intensity of capital-goods technology and concentration and openness of the sector. At the individual firm level, a patent analysis of the catch-up experience of Samsung by Joo and Lee (2010) proved that a catch-up in technological capacity precedes a catch-up in sales or market value in the case of Samsung's catch-up with Sony.

All of these studies are significant intellectual contributions that offer insights into the catch-up experience of individual nations, sectors and firms. However, they fell short of providing the kind of micro-level framework offered by a firm-level analysis. To obtain a clearer understanding of dynamics of catch-up at the national and sector-level attempted by earlier studies, we need a micro-level analysis applied at the firm level: examining the catch-up experience of a specific firm from a specific sector of a country. From such a perspective, this study intends to take a bottom-up approach using firm-level data to identify a set of possible patterns of inter-firm catch- up and discuss how these possible patterns relate to the ones identified at the sectoral level by a top-down approach.

One important condition for a successful catch-up at the firm level is the advent of a new technological paradigm. This can be attributed to the opportunity to leapfrog provided to latecomer firms during this period, which helps them bypass the old technological trajectory and tap directly into new, high growth-potential sectors (Perez and Soete, 1997). However, such a window of opportunity, i.e. a technological paradigm shift, alone does not guarantee the success of the development leap nor an eventual catch-up. Room for entry does not open up until that window of opportunity is overlooked by an established leader in the incumbent trap. Another important factor is the strategy employed by latecomer firms in their pursuit of catch-up during this transition. The outcome will also vary depending on the characteristics of a specific sector or the regime. This brings us to the conclusion that, if latecomer firms are to come out on top of the incumbent after the transition, all the required conditions above must be met at the time of the decision to take advantage of the opportunity created.

To be sure, sizable body of literature already exists that offers an extensive analysis of the technological catch-up of latecomer countries through the establishment of theoretical hypotheses and models which hold implications for government policies and corporate strategies. Text book level examples of such works include Economics of East Asia and Technological Catch-up (2007) and Schumpeterian Analysis of Economic Catch-up (2013). Some studies have also been conducted to analyze what happens in the process of a catch-up, but the papers dealing with this topic have given only fragmentary explanations.

Therefore, the task of this study is to specifically try to formulate a set of possible patterns at the individual firm-level in the process of catch-up through patent analysis, followed by an empirical analysis to identify some meaningful results in the process of catch-up for the firms.

To fulfill this purpose, we divided our primary research question into the following four research questions, reviewing previous studies:

1) Are latecomers able to catch up with forerunners in the market without technological capabilities?

2) Do latecomers utilize technologies that are similar to or distinct from those employed by forerunners?

3) Is it necessary for latecomers to invest in cutting-edge or more recent technologies in order to catch-up?

4) Do science-based technologies increase over time during the catch-up process?

Looking for the answer to the above research questions, this study made an in-depth analysis of the catch-up phenomenon at firm level from a technological perspective using patent data, which has been used widely in recent times, and reviewing existing catch-up theories.

We first looked for several cases in different sectors, in which latecomers in developing countries were able to catch up with the leaders in developed countries; to examine whether a set of possible patterns exist that occur in the catch-up process. An in-depth analysis of patents filed and cited by two comparison target firms followed. This paper is organized as follows. First, in chapter two, the literature is reviewed and research questions are raised. In chapter three, patent analysis methods like, the quantity of patents, the quality of patents, backward citation lag and citation of non-patent literature as science-base are explained. Chapter four shows the process and results of the patent data analysis of the eight companies. Chapter five investigates answers to the research questions based on the preceding analysis and presents a set of possible patterns followed in the technological catch-up process from the four catch-up cases. Finally, chapter six concludes the paper.

Chapter Two
Literature and Motivation

1. Previous Literature

Interest in latecomers in economic development begins with Gerschenkron (1962, 1963) and Abramowitz (1986), who mainly emphasized the advantages of latecomers. In the case of those industries where mature production method have already been established based on a large amount of capital, latecomers are able to utilize a mass production system from the beginning. These explanations are in accord with Vermon (1966), who advocates a product life cycle.

Schumpeterian scholars make up the school which approaches the theme of catch-up theoretically through practical analysis. After the publication of Nelson and Winter (1982), several scholars have studied the phenomenon of economic catch-up, one of the most important elements of which is knowledge based on the Schumpeterian perspective. The school went through several studies, including Malerba (2002, 2004), Lee and Lim(2001), Lee, Lim, and Song (2005), and K Lee(2001, 2005), and evolved into the Neo-Schumpeterian school, which emphasizes innovation and technological capabilities as important elements in the catch-up phenomenon. They lay emphasis on the concept of a technological regime, which argues that although innovation and technological capabilities are important in catch-up, characteristics of technology are different by sector and therefore, technological innovations can differ by sector in content and pattern.

The concept of a technological regime was born in Nelson and Winter (1982:258) and considered similar to the technological paradigm presented in Dosi (1982). Later on, Malerba, and Orsenigo(2000) defined a technological paradigm as a particular combination of key dimensions, which are technological opportunity, appropriability of innovation, competitiveness of technological advances and properties of a knowledge base. According to the Neo-Schumpeterian, a technological regime is a concept that provides a good explanation of the formation process of innovative activities.

The catch-up phenomenon may occur on three different levels-national, sectoral and firm levels. The analysis of catch-up at the national level is called national innovation system(NIS), which sees the difference in each nation's NIS as the cause of their different catch-up courses and speeds (Lundvall, 1992 :Nelson, 1993; et al). A NIS is a set of several systems which influence the innovation ability of a nation. The concept includes several components such as R&D capacities of domestic firms, the finance system that supports innovative firms, the education system, and the quality of government services.

The success or failure of different countries may differ according to different sectors, which is an important component in the concept of a sectoral system of innovation (SSI) (Malerba, 2004). It provides evidence of as to why the outcomes of innovation and catch-up differ according to different sectors. For example, Korea has succeeded in developing some sectors, but failed in developing others. This concept begins with giving attention to the phenomenon that different sectors develop differently in the same country. In order to analyze such differences, a thorough understanding of the characteristics of innovative activities in each sector is needed. However, most analysis regarding this matter has focused on developed countries (K Lee, 2007) and as such is not relevant to the study of developing countries. Park and Lee (2006) adapted the concept of a technological regime, by which they mainly analyzed the characteristics of sectors in developed countries, and developed a new analysis model which they applied to the case of Korea and Taiwan. This paper proved empirically that Korea and Taiwan showed good outcomes in sectors with short technology cycles.

Technological catch-up analysis at the firm level focuses on how firms in developing countries absorb existing knowledge from overseas, spread it within their country, and create new knowledge based on that existing knowledge. Mathews (2002a) and Lee and Temesgen (2009) conducted an analysis at the firm level regarding the successful outcomes of firms from several developing countries. However, they did not compare such firms with firms from developed countries and only analyzed the firms which found success due to comparative advantages such as low production costs. K Lee, (2013) provides a comprehensive analysis of the catch-up process at the national, sectoral and firm level and case-by-case analyses at different levels in each chapter in his book, Schumpeterian Analysis of Economic Catch-up. Of particular note is a study by Joo and Lee (2009), where they conducted a firm-to-firm matching analysis. This study dealt with Samsung's catch-up with Sony using an in-depth analysis of the technological aspect using US patent data.

This paper follows the same approach methods with Joo and Lee (2009) in two aspects; it utilizes a firm-to-firm matching analysis and patent data. Following this methodology, we try to draw meaningful results by examining a variety of cases of catch-up.

2. Research Questions and Distinctives of the Current Study

This research questions pursued in this study began with the researcher's curiosity as to how a firm in a developing country can catch-up with the leading firms in advanced countries and even become a leader of industry. Firms in developing countries generally face many unfavorable conditions such as poor production technological or innovative capabilities, poor product quality and marketing capabilities, and low brand value. In fact films in developing countries may have little advantage at all except for their low labor costs. At first glance, it seems nearly impossible that such firms could catch up with the leading firms in advanced countries, but instances of the catch-up phenomenon do sometimes occur. Previous literature has dealt with this catch-up phenomenon between firms and suggested various viewpoints about the reasons for it. Several studies have been conducted that have looked into what happened in the process of catching-up, but the papers dealing with this topic have only provided fragmentary explanations.

This paper tries to give answers to the question of the catch-up success of latecomers by investigating cases of successful catch-up firms and doing a firm-to-firm matching analysis at the firm level using patent data to investigate an aspect of the phenomenon that previous studies have little dealt with. The main research question, "What process do successful catch-up firms follow?" can be divided the following four questions, based on previous research.

The first question is that of whether latecomers without technological capabilities are able to catch-up with market forerunners. This question is closely related to the question: of whether latecomer firms can catch up with market leaders more quickly by capitalizing on low wages (and thus low production costs) rather than technologies. Traditional management theories have emphasized in advantage in the production costs as the basis for a competitive edge. This approach comes from an economics or business perspective which regards price as the most basic means of competition among companies.[1] The fact that several leading conglomerates sought to secure more interests through mass-production and a large transaction by economy of scale and scope in the 20th century does show the importance of the advantage of production costs. In addition, recent trends show that such companies have tried to achieve production cost advantage through various means such as downsizing, restructuring and outsourcing.

The factors that determine an advantage in production costs include economy of scale[2], expansion of market share[3], and a competitive edge in the cost of production components[4]. Scherer(1980) emphasizes that the concentration ratio increases gradually in the sector with apparent economy of scale by looking into the minimum efficient scales and concentration ratios in each sector. Yells (1979) found that production costs decrease as the accumulated output increases. In addition, Buzzel, Gale and Sultan(1981) revealed an intricate correlation between market shares and the earnings rate of a company through a practical study of the profit impact of market shares. Wells (1983) and Agmon and

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[1] Chang, 2007

[2] Scherer, 1980, Yells, 1979

[3] Buzzel, Gale and Sultan, 1981

[4] Wells 1983, Agmon and Kindleberger, 1977

Kindleberger (1977) mention ways to secure a competitive edge in the cost of production components, pointing out that companies in advanced countries tend to mass produce a limited variety of items through a standardized production process, while those in developing countries tend to produce greater variety of items in small quantities through a flexible production process.

Gerschenkron (1962, 1963), and Abramovitz (1986), which helped garner more attention for developing countries in the realm of economic development, point out that latecomer firms have advantages related to economy of scale in the steel industry. This perspective is similar to the points made about product life cycle theories by Vermon (1966), Utterback and Abernathy (1975), and Wesphal and Kim (1985). These theories put more emphasis on catching up in the low-end market based on the advantage of low production costs. In fact, many multinational corporations have taken advantage of countries in Southeast Asia and China as their production base and commodities market.

In light of the limitations of catch-up based on low production costs, several recent studies have explored accumulated technological capabilities as the basis for catching-up, including the Schumpeterian like Malerba (2002, 2004), Lee and Lim (2001), Lee, Lim, and Song (2005), and K. Lee (2001, 2005). These studies emphasize innovation and technological capabilities as important elements in successfully catch-up and emphasize the concept of a technological regime, which argues that although innovation and technological capabilities are important in catch-up, different characteristics of technology in each sector lead to different technological innovation in its content and pattern.

At a national level, Spece (2011) points out the limitations of labor intensive export-led industrialization based on low wages. Such a method makes it difficult for firms to maintain their dominance without innovation capabilities, though, due to the rise in the wages caused by their early success and the emergence of other competitive underdeveloped countries. Few developing countries overcome these crises and find themselves stuck the middle-income trap, in which income stagnates. Latin America, a few countries in Southeast Asia and Mauritius in Africa represent such cases[5].

Beside those researchers in the Schumpeterian school, several others have emphasized the importance of accumulated technological capabilities in catch-up.

Saviotti and Metcalfe (1984) try to establish the nature of technological development and O'Neil (1993) emphasizes the radical innovation of technologies in the United States, pointing out the importance of technological capabilities. Cooper and Schendel(1976) also emphasize the importance of technological capabilities in dealing with how existing corporations become faced with threats during the technological innovation process, and argue that the dual strategy of seeking to develop existing technologies and new ones simultaneously is not effective. Generally, the strategy of seeking to develop products using new technologies while improving existing technologies imposes a significant difficulty on the product sector using new technologies. Wheelwright and Clark (1992) arrange and suggest the roles that corporate leaders should play in each technological development stage. These studies which try to understand corporations in terms of technology account for the catch-up phenomenon of each company in an organized and detailed way. However, existing literature lacks concrete and practical tests about the order in which events occur related to catch-up in the market and catch-up technologically. Assuming

[5] Lee, 2013

the importance of accumulated technological capabilities in catch-up among firms, comparing the point of catch-up in the market and that of technological catch-up through the in-depth analysis of successful latecomer firms is very meaningful. Therefore, this paper tries to compare the point of time of catch-up in the market and that of technological catch-up with the first question occurring in the catch-up process for several firms.

This paper also mentions various companies, such as Daewoo Motors, Proton Motors in Malaysia (stuck in the middle-income trap), and Bethlehem Steel in the United States[6], which developed themselves based on low productions cost rather than accumulated technological capabilities. These three firms are examples of companies that have failed to upgrade themselves in order to enter a new, high added-value industry[7], so the analysis of successful latecomer firms will prove the order of incidence between catch-up in the market and technological catch-up in detail. This approach is in sharp contrast to existing literature.

The Second research question that will be explored is: that of whether latecomers who are successful in catching-up based on technological capabilities, use technologies that are similar to or different from those employed by forerunners. It is generally known that during the technological catch-up period, especially in its initial stage, latecomer first imitate the technologies used by forerunners, then modify that technology, and finally develop their own technology[8]. Can this statement be applied to all catch-up cases? Several existing studies provide some insight. One such insight is the concept of technological

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[6] Jim Collins, 2009, How the mighty fall

[7] Lee, K. and J. Mathews, (2012) mentioned this in the nation level, not firm level.

[8] Lee, 2008

catch-up in terms of the quality of patents. By examining patents, one can identify whether the new or modified technologies are better or not, attempting to validate the use of patent citations as indicators of economic impact or value. Patent documents contain references to previous patents, i.e. patent citation. They indicate which parts of the described knowledge are claimed in the patent, and which parts have been claimed earlier in other patents (Verspagen, 2007). A reference to a previous patent indicates that the knowledge in the latter patent was in some way useful for developing the new knowledge described in the citing patent (Jaffe, 2002). Citations received may be telling of the importance of a cited patent (Hall, 2001). Trajtenberg (1990) related the flow of patents in computed tomography (CT) scanners, a major innovation in medical technology, to the estimated social surplus due to improvements in this technology. Whereas simple patent counts showed no correlation with the estimated surplus, citation-weighted patent counts turned out to be highly correlated with it, thus providing first-time evidence to the effect that citations carry information on the value of patented innovation(Hall, Jaffe and Trajtenberg, 2005). Recent work by Lanjouw and Schankerman (2003) also uses citations as an indicator to verify the value of a certain piece of technology, along with other measures such as number of claims and number of countries in which an invention is patented, as a proxy for patent "quality." They find that a composite measure has significant power in predicting which patents will be renewed and which will be litigated, thus inferring that these indicators are associated with the private value of patents (Hall, Jaffe and Trajtenberg, 2005). Harhoff et al. (1999) surveyed German patent holders of US patents that were also filed in Germany, asking them to estimate the price at which they would have been willing to sell the patent right three years after filing. There also exists a substantial literature relating the stock market value of firms to various measures of "knowledge capital,' and in particular to R&D and patents, going back to the landmark research program initiated by Griliches et al. at the NBER(Hall, Jaffe and Trajtenberg, 2005). Hall(2000) offers a recent survey of this vein of work: the typical finding of which is that patent counts do not have as much explanatory power as R&D in a market value equation, but they do appear to add some information above and beyond R&D figures. A few papers have tried to incorporate patent citations as well, albeit in the context of small-scale studies (Hall, Jaffe and Trajtenberg, 2005): Shane (1993) finds that, for a small sample of semiconductor firms during the period of 1977-1990, patents weighted by citations have more predictive power in a Tobin's q equation than simple patent counts, even when R&D stock is included. Citations-weighted patents also turned out to be more highly correlated with R&D than simple patent counts, implying that firms invest more efforts into patented innovations that ultimately yield more citations (Hall, Jaffe and Trajtenberg, 2005). Austin (1993) finds that citation-weighted counts enter positively but not significantly in an event study of patent grants in the biotechnology industry. Hummon and Doreain (1989) analyze the network of citations between scientific publications on the discovery of DNA to construct a main path. Verspagen (2007) use the US Patent Office database to map the citation network in fuel cells using patent citations to map technological trajectories in fuel cells. At the firm level, Joo and Lee (2009) which made a firm-to-firm matching analysis at the firm level compared Samsung and Sony in the terms of quality of patents using US patent data. The quality of the two firms' patents can be measured by the average number of received citations. A variety of research shows that the quality of two firm's patents can be measured by the average number of received citations, because the more a patent is cited, the more it is considered to be of value or worthy of use(Albert et al.,1991). R&D reveals the commitment of a firm's resources to innovation, patents catalog the success in generating codifiable new knowledge that can in principle be appropriated by the firm, and citations indicate the extent to which those innovations turn out to be "important" and hence presumably more valuable to the firm (Hall, Jaffe and Trajtenberg, 2005).

The aforementioned literature uses patent citation as an indicator of technological worth. So, the better technologies in terms of quality of patent that the research raised can be viewed as technologies of good quality.

Comparing the quality of two firms' patents is definitely a good way to confirm the importance and quality of their technology in terms of patent quality. Such information, however, still not sufficient to confirm whether or not latecomers can catch-up with forerunners based on their development or use of "different" technologies during the catch-up process.

Therefore, for the purposes of this study, we seek to evaluate the importance of different technologies in catch-up by measuring the level of technological dependence and self- citation ratio of different films.

The level of technological dependence is reflected in the citation patterns between the catch-up firm and the leading firm. Changes in technological dependence are examined by the citation patterns between the two firms. The more the catch-up firm imitates the leading firm, the higher the level of technological dependence is. Based on this reasoning, the completion of the catch-up technically would mean a change in the citation pattern where, the catch-up firm and the leading firm equally cite each other's patents. If the proportion of the leading firm's citations of the catch-up firm's patents increases, whereas the share of the catch-up firm's citations of the leading firm' patents decreases over the years, this trend shows that the catch-up firm is becoming more independent from the leading firm, and the leading firm is becoming more reliant on the catch-up firm.

The self-citation ratio indicates a firm's ability to protect its innovations from being copied by others, thus monopolizing any profits from the innovations. The lower the self-citation ratio is, the higher the vulnerability of the designs to being copied, and thus the lower the profits that can be reaped from the innovation. The self-citation ratio can be measured as the proportion of self-citations out of total citations (Trajtenberg et al., 1997).

In this paper, we chose to verify a whether a firm's technological capabilities are from similar or different technologies, by considering the level of technological dependence between two firms, and the self-citation ratio of the latecomer and the number of received citations for patents.

The third question that will be asked in this study is whether or not it is necessary for a catch-up firm to invest in cutting-edge or more recent technologies in order to successfully catch-up.

How do we define recent technology? Technically, the technology cycle of a patent measures how recent or up-to-date the technology is that a patent is based on, and shows a firm's reliance on more recent technology (Narin, 1994). The backward lags focuses on the time difference between the application or grant year of the citing patent, and that of the cited patents (Hall, Jaffe and Trajtenberg, 2001). Backward citation lag represents how recent the patents are that are cited in a patent that a firm files, while forward citation lag indicates how quickly the patent is cited in other following patents. These two indicators show how fast a firm obtains new technologies, recreates them and develops their own technologies utilized by other technologies in the process of a technological catch-up. Joo and Lee (2009) also use the information of patent citation as an indicator of more recent technologies, when comparing the patents filed by Samsung and Sony. Therefore we use the backward citation lag as an indicator of up-to-date or more recent technologies.

On this third research question, some answers do already exist regarding the sectoral and national levels. Park and Lee (2006) addressed this question in a paper where they adapted the concept of a technological regime, which mainly analyzed the characteristics of sectors in developed countries, and developed a new analysis model which was applied to the case of Korea and Taiwan. Park and Lee used the concept of technology cycles to prove empirically that Korea and Taiwan showed good outcomes in sectors with short technology cycles, but made no mentions of the firm level. In this paper, we seek to determine whether this result can be applied to firms within the same sector. Chapter five in this paper will answer this question.

The fourth question is whether the increase in a latecomer's science-based technologies over time accelerates the catch-up process. Some technologies can be classified as coming from basic science, not application technology. In order to figure out whether a catch-up firm's science-based technology is increasing or not during the catch-up process, one can construct citations-based measures that may capture other aspects of the patented innovations, such as "originality", "generality", and "science-based", (Trajtenberg et al., 1997). Among them, citation of non-patent literature can be used as an indicator of the strength of a company's basic science base. The higher the figure is, the stronger that firm's science base is. Most non-patent literature consists of scientific papers in academic journals.

The differences between our study and those of other scholars' are as follows. First, our study focuses on the sustainability of the catch-up phenomenon through empirical studies. The fact that latecomer firms catch up with market leaders based on their accumulated technological capabilities has been mentioned in other literatures. However, few of them point out that technological catch-up tends to precede catch-up in the market and that catch-up based on low wages rather than technology cannot continue. By noting the specific catch-up cases of various companies and the catch-up cases based on technology rather than the advantage of low production costs based on low wages, our paper provides potential late-comers with implications or a catch-up strategy in various sectors.

Second, our analysis shows the possibility of patterns within the same sector as well as between sectors. Existing literature mention the difference in catch-up patterns in different sectors. Park and Lee (2004) demonstrated that catch-up happens in sectors with fast technology cycles such as in the cases of Korea and Taiwan. However, this paper differs from previous studies in that it deals with whether such patterns exist within the same sector, as well as between sectors by pointing out that in the IT sector, the catch-ups of Huawei and Samsung have been based on up-to-date technologies with fast backward citation lag, while in non-IT sectors, Hyundai Motors and POSCO followed different catch-up patterns than did Huawei and Samsung.

Chapter three
Methodology

1. Introduction

Among other indicators, R&D expenditures, patent statistics, new product introductions, and a combination of the aforementioned have been widely used to measure a firm's technological capabilities
(Schoenecker and Swanson, 2002). Because patents and patent citations provide detailed information about the inventions and innovations, and cover a relatively long period of time as well as virtually all fields of technology (Griliches, 1990), they have long been accepted as a reliable, though not perfect, source of information to measure a firms' technological capabilities (Naren et al., 1987; Patel and Pavitt, 1997).

Patents also provide an extremely wide coverage in terms of technologies, assignees, and geography(Hall, Jaffe and Trajtenberg, 2005)

On these grounds, we analyzed the patents of firms and related citations. Patents filed by firms can be mainly collected from the PATSTAT Database, which is constructed by the European Patent Office (EPO) and other database sources. The patents are recognized according to their application year, considering time of invention.

We specifically analyzed patents filed and registered at the EPO from the PATSTAT database and U.S. patent data to investigate when and how the late-comer firms in our case study pairs caught up with incumbents in terms of quantity and quality of patents. We analyzed the number of registered patents to analyze the firm's technological catch-up in terms of quantity and conducted a patent citation analysis to analyze the catch-up in terms of quality.

Few previous studies on the catch-up phenomenon explored the idea of sustainable catch-up. To do so however, we must first define technological catch-up in more detail. According to Park and Lee (2004), technological catch-up is defined in the nation level: technological catch-up countries are countries where the economy succeeds in generating technological innovation more rapidly than the economies of advanced countries. Although most developing countries have attempted to achieve technological catch-up, the majority have made little progress. In this paper, though, we are exploring the issue catching-up at the firm level, so we have to view technological catch-up from the perspective of a single firm. At the firm level, technological catch-up generally occurs in three different ways. The first type of technological catch-up happens when the latecomer's products outperform those of leading firms. In this case, the quality of the latecomer's products is marked by differentiation, which means that the latecomer makes better products. For example, Samsung's Smart TV is better than Sony's and Huawei Technologies' telecommunications equipment performs better than that of Ericsson in the Sahara Desert.

The second type of technological catch-up happen when a latecomer lowers their production costs by improving existing production methods, or operating technology, or developing new ones. For example POSCO invested in cost saving technologies for a long time and finally invented the COREX and FINEX[9] methods of steelmaking which save a lot of

[9] Song, Sungsoo (2010). From COREX to FINEX: The Case Path-revealing Innovation in

energy and enhance productivity. This allowed POSCO to catch- up with Nippon Steel 10 years later. The final type of technological catch-up occurs when a latecomer has a more diversified portfolio of its products than the leading firms do. These three types of technological catch-up are made possible by accumulated technological capacities or technological developments and the usual expression of these technological progresses is expressed as patent information. Therefore, this paper mainly uses patents as indicators of technological catch-up. To analyze catch-up in terms of the quantity of a firm's patents, the number of granted patents held by the firms was examined, according to the year the patents were filed in (Joo and Lee 2009). Even though it has long been known that innovations vary enormously in their technological and economic importance, significance or value, the distribution of such values is extremely skewed (Hall, Jaffe and Trajtenberg, 2001). There other serious limitations to this method, the most significant being that not all innovations are patented, simply because not all inventions meet the patentability criteria, and because the inventor has to make a strategic decision to patent, as opposed to relying on secrecy or other means of appropriability (Hall, Jaffe and Trajtenberg, 2005) These concerns shows that patent data has stringent limitations. Therefore, in a sector like the steel industry which relies more on tacit knowledge than patents, we use other technological indicators like productivity to answer the research question.

POSCO. Chang(2007), Strategic Management in the Age of Global Competition.

2. Patent Data analysis and Previous Literature

1) Making Sense of Comparison

It's very important to confirm that two firms compete in similar technological areas before making further comparison of the two.

Therefore, we performed a verification to examine the level of technological similarity of their patents. It is an essential to compare and analyze the technological characteristics of the first mover and the fast follower by using patent portfolio statistics. To do this, we measured the technological proximity of the two firms.

The related literature states that the level of competition between two firms can be considered high when the firms rely on similar sets of technology (Podolny et al., 1996). The level of technological competition between firms can be analyzed by the technological proximity (Jaffe, 1986) and technological overlap (Mowery et al., 1998) between them.

The technological proximity between the two firms was measured by the technological proximity measure suggested by Jaffe (1986).

$$\text{Technological proximity}_{ij} = \frac{\sum_{t=1}^{T} P_{it}P_{jt}}{\sqrt{\sum_{t=1}^{T} P_{it}^2}\sqrt{\sum_{t=1}^{T} P_{jt}^2}}$$

P_{it} : the share of firm i's patents in the technological field t among the total patents of firm i

T : total number of technological fields

The technological proximity between two firms is measured as a value between 0 and 1. The higher the value is, the more similar the two firms are in technological specialization, and vice versa.

The degree of technological overlap between the firms was measured by the common citation rate suggested by Mowery et al. (1998)

Common citation rate:

$$= \frac{\text{Citation in firm I's patents to patents cited in(or citing)firm j' patents}}{\text{Total citations in firm I's patents}}$$

$$+ \frac{\text{Citation in firm j's patents to patents cited in (or citing) firm I's patents}}{\text{Total citations in firm j's patents}}$$

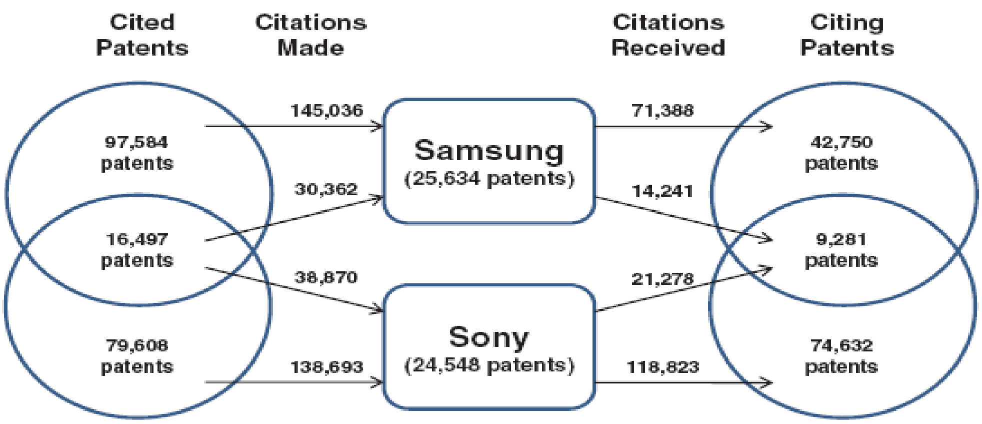

Figure3.1 Citations of Samsung Electronics' and Sony's patents (Joo &Lee 2009)

The technological overlap between two firms measures the degree to which two firms' technologies are based on, or applied to, the same technology pool and is measured as a value between 0 and 1. A higher rate means that the technologies of the two firms greatly overlap.

Joo and Lee paper (2009) discuss the citations of the two firms' patents. Samsung Electronics made a total of 175,395 citations. Among these citations, 30,362 (or 17.3%) were directed at patents

In terms of the citations made by the two firms, the technological proximity value was 0.39, and, in terms of the citations received by the two firms, the technological overlap value was 0.32. Given that, according to Mowery et al. (1998), the average common citation rate between firms is less than 0.1, rates higher than 0.3 should be taken as very high, implying that the technological competition between the two firms is very intense. As such, these technological proximity and overlap values demonstrate that it is reasonable to compare two firms technologically.

2) Catch-up in terms of quantity of patents

Technological catch-up generally happens in three ways. The first happens when the product performance of the latecomers excels that of the leading firms in existing products. In this case, the quality of the products of the latecomer has differentiation, which means that the latecomer makes better products. The second happens when latecomers lower their production costs by improving existing production methods or developing new ones. The last means happens when the latecomer has a more diverse portfolio of products than the leading firms. These three cases are made possible by accumulated technological capacity or technological development, the usual expression of which is patent information. The analysis of more than 10 years of long-term changes in patents makes it possible to observe this phenomenon. Therefore, this paper uses patents as indicators of technological catch-up.

To analyze catch-up in terms of quantity of the firm's patents, the number of granted patents held by the firms, according to the year the patents were granted, was examined.

3) Catch-up in terms of the quality of patents

The quality of a firm's patents can be measured by the average number of citations received. A variety of research shows that the quality of two firm's patents can be measured by the average number of citations received, because the more a patent is cited, the more it is considered to be of value or worthy of use(Albert et al.,1991).

4) Technology cycle (Backward citation lag)

The technology cycle of a patent measures how recent or up-to-date the technology is that a patent is based on, and shows a firm's reliance on more recent technology(Narin,1994).

$$\text{The backward citation lag of patent i} = \sum_{j=1}^{\text{nciting}_i} \frac{\text{LAG}_j}{\text{NCITING}_i},$$

NCITING_i= Total citation made by patent i

LAG_j = difference between the filing date of citing patent i and the filing of cited patent j

Backward citation lag represents how recent the cited patents are in a patent that a firm files, while forward citation lag indicates how quickly the patent is cited in other following patents. These two indicators show how fast a firm obtains new technologies, recreates them and develops their own technologies utilized by other technologies in the process of a technological catch-up.

5) Level of technological dependence

The level of technological dependence is reflected in the citation patterns between a catch-up firm and a leading firm. Changes in technological dependence are examined by the citation patterns between two firms. The more the catch-up firm imitates the leading firm, the higher the level of technological dependence is. Based on this reasoning, the completion of a catch-up technically would mean a change in the citation pattern, such that the catch-up firm and the leading firm equally cite each other. If the proportion of the leading firm's citations of the catch-up firm's patents has increased, whereas the share of the leading firm's citations of the leading firm's patents has decreased over several years, this shows that the catch-up firm is becoming more independent from the leading firm, and the leading firm is becoming more reliant on the catch-up firm.

6) Self-citation ratio

The self-citation ratio reflects the capability of a firm protect its innovations from being copied by others, thus monopolizing any profits from its innovations. The lower the self-citation ratio is, the higher the vulnerability of the designs to being copied, and thus the lower the profits that can be reaped from the innovation. The self-citation ratio can be measured by the proportion of self-citations out of total citations (Trajtenberg et al., 1997).

7) Citation to non-patent literature as a science-base

One can construct citations-based measures to capture other aspects of patented innovations, such as “originality”, “generality”, and “science-based” , (Trajtenberg et al., 1997).[10]

Among them, citation of non-patent literature can be used as an indicator of the strength of a firm’s basic science base. The higher the figure is, the stronger the base is. Most non-patent literature consists of scientific papers in academic journals.

[10] There are technical challenges in measuring the originality and generality with European patents. NBER US patent data offers Main IPC class codes and use them as the criteria for measuring originality and generality. But European patent data has fundamentally institutionalized “equivalence classification,” in which multiple patent codes are listed on an equivalent basis, making it difficult to measure originality and generality.

Chapter four
Analysis of Patent Data for Target Firms

We selected pairs of latecomer and forerunner firms on the basis of two basic criteria. The first criterion was that the latecomer was able to catch up to the forerunner in terms of sales. The second was that the latecomer firms were firms from developing countries that caught-up with firms in developed countries, which is relevant to this paper's main research question. In addition, we considered the popularity of the firm and as such sought out well-known companies that fit the two basic criteria. After careful consideration, we took up four catch-up cases. Huawei's catch-up with Ericsson, Hyundai Motor's catch-up with Mitsubishi Motors, Samsung Electronics' catch-up with Sony, and POSCO's catch-up with the Nippon Steel Corporation. These eight companies are the cases are comparatively well-known and icons in their respective sectors. In addition, the success of the late-comers (Huawei, Samsung Electronics, Hyundai Motors and POSCO) has been described as dramatically as the story of David and Goliath by the media. The last reason why we selected these four cases is that the firms chosen are fierce competitors in their sector in similar technological fields and it is only recently that the latecomers have caught up with the industry leaders. In chapter four, we examine the catch-up process for each case and the results of the data analysis of the eight companies

1. Huawei's Catch-up with Ericsson

1) Introduction

Traditionally, the emergence of Chinese firms in the global market has been explained by their price competitiveness based on an abundant and inexpensive labor force. Contrary this common belief, though, a few Chinese firms have recently made an appearance in the global arena due to their technological competitiveness. Huawei, a new player in the telecommunications equipment industry, is a brilliant example. Despite being only a twenty-five-year-old Chinese firm founded in 1988 in the Chinese province Shenzhen with 14 employees and USD 3,000 of capital (Xu and Girling, 2004), Huawei took over first place in the global telecommunications equipment industry from Ericsson, which had held the top place for the past 100 years in 2012.

Huawei has been pursuing not only quantitative but also qualitative growth by strengthening its internal technological capabilities from the beginning, rather than by simply following the quantitative growth model typical of Chinese state-owned corporations based on government support, low-cost labor and a vast domestic market. Huawei ranked 5th among the world's 50 most innovative companies according to Fast Company, and won a Red Dot design award in the communication design category in 2010 along with Apple. In 2008, it also ranked first in the number of international patents filed through the Patent Cooperation Treaty (PCT).

This chapter investigates how this young firm caught up with Ericsson by analyzing the patents of Huawei and Ericsson (European patents granted from 2000 to 2010) and related citations.

Our analysis shows that Huawei's unrelenting accumulation of technological capabilities has been the crucial factor in its successful catch-up. Huawei overtook Ericsson in terms of the number of European patents (quantitative catch-up) in 2008, and in terms of average received citations of European patents (qualitative catch-up) as early as in 2000, when it began to file European patents. Our analysis also provided some evidence of Huawei's technology strategy. In comparison with Ericsson, Huawei developed technologies which were based on more recent technological developments, and were more quickly utilized in the market. In addition, by steadily increasing its technological independence, Huawei came to develop technology based on its own technologies rather than relying on others' technologies. Lastly, Huawei has taken full advantage of China's strong base in the basic sciences in its technological catch-up process.

In this chapter, we first provide a brief overview of Huawei and Ericsson, and then discuss Huawei's catch-up in the market. Next, we analyze Huawei's technological catch-up with Ericsson in terms of quantity and quality of their patents, and explore various dimensions of the two firm's technological catch-up such as technology cycle, appropriability and citations to non-patent literature as a science base. Finally, we discuss Huawei's strategies for supporting its technological catch-up.

2) Previous literature

There are several recent studies exist on the telecommunications equipment industry in China from diverse perspective (Mu and Lee, 2004; Liu,2006; Zhu et al., 2009; and Athreye and Chen, 2010). Mu and Lee discuss the telecommunications industry in China with a focus on knowledge diffusion and technological catch-up, while Liu observes the Chinese telecommunications industry in depth, reviewing the history of it from fixed phone switches to 3G. However, none of the aforementioned studies utilize patent data analysis. (Zhu et al. Athreye and Chen) discuss telecommunications equipment in China with a focus on the role of internalization and strategic innovation.

Other research focuses on Huawei itself in depth (Nakai and Tanaka,2010; Hoogen, 2010; Yeung,2005; Huang,2006; and Dickson and Fang,2008). Nakai and Tanaka approach Huawei's success from the perspective of the firm's IPR strategy using patent data, but do not investigate patent analysis at length, instead opting only to use the quantitative method to analyze some patents related to packet switching systems, WiMax and LTE. Hoogen, Yeung and Huang observe the internalization of Huawei as a key factor in the firm's success, but do not mention the technological approach. Dickson and Fang discuss another key factor in the firm's success in its management of its R&D..

Among the studies on technological catch-up at the firm level, one by Joo and Lee (2009), comparing Samsung with Sony explores the technological capabilities as one of the underlying factors for successful catch-up, although this study is not related to Huawei.

3) Huawei's catch-up with Ericsson in the telecommunications equipment industry

3)-1 A brief introduction to Huawei and Ericsson

A recent notable trend in some industries in China is the emergence of new private firms with global competitiveness. Huawei, a new major player in the telecommunications equipment industry, is a shining example. Huawei is a young, globally competitive private firm which has been pursuing qualitative growth by strengthening its internal capabilities, such as R&D and intellectual property rights, from the beginning, rather than following the volume growth model typical of Chinese state-owned corporations based on government support, low-cost labor and a vast domestic market. To stay away from fierce competition in the domestic market and focus on the global market, the firm is focused on developing technologies on its own, rather than taking advantage of the country's cheap labor. A tangible outcome of such efforts is that it ranked 5th among the world's 50 most innovative companies selected by Fast Company and won a Red Dot design award in the communication design category in 2010 along with Apple. In 2008, it also ranked top in the number of international patent filings through the PCT. This paper offers an analysis of how this young firm which only 20 years after its founding, caught up with Ericsson the number one telecommunications equipment marker over the past 100 years.

A brief introduction to Huawei

Huawei, also called the "Chinese HP (Hewlett-Packard Company)" by the media, was established in 1987 by Ren Zhengfei, a former People's

Liberation Army (PLA) communications officer, and five of his fellow PLA members. The firm began as a telecommunications equipment dealer on a farm in Shenzhen, where the founders imported HAX from Hong Kong and sold it domestically with the start-up capital of only RMB20,000 (approximately USD 3,000)

The company laid the foundation to transform itself into a telecommunications equipment manufacturer by developing "C&C 08," a program-controlled telephone switching system in 1993. By expanding its business into new areas, such as routers, telecommunications equipment and handsets, it has become a world-class telecommunications equipment maker in terms of both business and technological capabilities.

In 2008, Huawei filed 1,737 international patents through the PTC, the making it the largest filer of such patents in the world.[11] It also ranked fifth in sales in the global telecommunications equipment market (including handsets) in 2009[12] and posted USD 12.3 billion in sales, the second highest amount in the global telecommunications equipment market excluding handsets in 2010.[13] All these suggest that the firm has achieved outstanding growth in the less than 30 years since its founding.

[11] http://www.wipo.int/pct/en/newslett/2009/02/article_0001.html

[12] Gartner, "Market Insight: A Snapshot Review of the Top Telecom Equipment Vendors, Worldwide, 2Q10 Update", 29 Jun. 2010

[13] Gartner, "Market Share: Carrier Network Infrastructure, Worldwide, 2010", 22 March 2011

A brief introduction of Ericsson

Ericsson is the undisputed world leader in the telecommunications industry. It is no exaggeration to say that the history of Ericsson is the history of the global telecommunications industry. The firm was founded in 1879 by Lars Magnus Ericsson as a telegraph equipment repair shop in Stockholm, Sweden. As the Swedish domestic market was limited, the firm began reaching out to the world in as early as 1890. 1897, global sales accounted for 81% of its total sales.[14]

Competing with Bell in the international telephone and switching systems market, Ericsson emerged as a leading player in the telecommunications industry after commercializing the 1st-generation analogue mobile phone in 1981. Since becoming a world-class firm in the late 1990s based on the rapid growth of the telecommunications and internet industries, Ericsson has become a major telecommunications equipment vendor with a market capitalization of USD 210 billion in 2000, the equivalent of 8% of the total GDP of Sweden.

The firm posted USD 23.8 billion in sales in 2009, the 4th largest in the global telecom equipment market[15] (including handsets) and USD 15.4 billion excluding handsets, ranking first in the market.[16]

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[14] Institute for Information Technology Advancement, "Trends of the Global Telecommunications Equipment Market and Among its major Vendors", February 2009 (in Korean)

[15] Gartner, "Market Insight: A Snapshot Review of the Top Telecom Equipment Vendors, Worldwide, 2Q10 Update", 29 Jun. 2010

[16] Gartner, "Market Share: Carrier Network Infrastructure, Worldwide, 2010", 22 March 2011

3)-2 Huawei's catch-up in the telecommunications market.

Sales revenues are typically used as indictors of catch-up in a market, which Joo & Lee (2009) confirms. This study uses sales revenues and the point of time that the latecomer overtakes the leading firms in sales revenues as the criteria for judging a catch-up in the market and the point of time at which the catch-up happens.

Huawei became one of the top ten telecommunications equipment vendors (including mobile handsets) in terms of sales for the first time in 2007 and ranked fifth in 2009 (See Table 4.1). However, Huawei holds second place in the network equipment market in terms of market share, lagging only Ericsson in the telecommunications equipment market excluding mobile handsets, in 2010 (See Table 4.2).

Table 4.1 Annual sales of major telecom equipment vendors, including handsets (2000~2009)[17]

Ranking in 2009	Vendor	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
1	Nokia	56.96	69.62	56.89	50.56	41.60	35.86	33.29	28.33	27.63	27.45
2	Cisco	35.29	39.58	31.30	31.33	25.76	23.36	19.59	19.24	18.93	23.11
3	Samsung	26.90	24.69	21.07	19.03	18.46	16.51	11.92	9.94	6.99	6.73
4	Ericsson	23.27	29.91	17.09	18.91	15.11	14.67	11.75	12.03	22.08	29.26
5	Huawei	21.82	18.33	12.56	7.70	5.30	3.83	2.69	2.13	2.06	2.66
6	Motorola	20.62	28.46	30.94	38.32	27.62	23.45	16.27	16.43	18.42	22.77
7	Alcatel -Lucent	19.48	24.36	18.92	19.66	20.74	20.27	19.12	23.99	40.68	47.91
8	RIM	14.46	10.23	n.a.	n.a.	n.a.	1.22	n.a.	n.a.	n.a.	n.a.
9	NEC	12.59	13.76	9.92	12.37	16.59	17.05	15.86	12.10	17.43	16.03
10	LG	11.98	13.33	11.89	9.27	8.04	8.10	9.82	3.56	3.03	2.56

Table 4.2 Major Vendors in the Network Equipment Market in 2010[18]

Ranking	1	2	3	4	8
Vendor	Ericsson	Huawei	Alcatel-Lucent	Cisco	Samsung Electronics
Market share	19.6%	15.7%	13.3%	9.3%	2.5%

Slowdown in the global telecommunications equipment market in the early 2000s

[17] As mentioned above, Table 4.1 includes the sales of mobile handsets. If excluding mobile handsets and looking only at telecom network sales, Ericsson had the largest market share, with Huawei closely trailing in the 2nd place.

[18] Gartner, “Market Share: Carrier Network Infrastructure, Worldwide, 2010”, 22 March 2011

As the bubble burst in the information and communications industry in the early 2000s, investment in the telecommunications sector showed a sharp decline. OECD member countries cut their investment in telecommunications by 41% over three years, from USD243.2 billion dollars in 2000 to USD142.3 billion in 2003 (See Figure 4.1). Due to such a drastic slowdown of the downstream industry, the sales of major telecommunications equipment vendors[19]dropped by over 30% over the same period. If the sales of Nokia, whose mobile handset sales represent a high percentage of total sales, are exduded, the figure fell further to 41%.

Figure 4.2 (a) clearly indicates the severity of the downturn. Total sales of major telecommunications equipment vendors fell sharply in the early 2000s. Sales excluding Nokia dropped very rapidly as well.

Figure 4.2 (b) shows the sales trend of individual vendors. As can be seen in the graph, the downturn of the industry caused by the economic recession of the early 2000s was quite serious. Nokia's sales increased only because its main business area was handsets, and as such cannot be viewed as sales growth in the telecommunications equipment market.

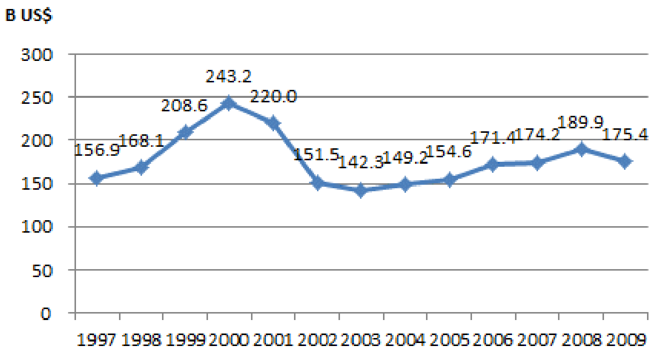


Figure 4.1 Telecommunication Investments of OECD Countries[20]

[19]"Major telecommunications equipment vendors" refers to telecommunications equipment firms that have posted at least USD 10 billion in sales as of 2000.

[20] Source: OECD(2011), Telecommunication Outlook

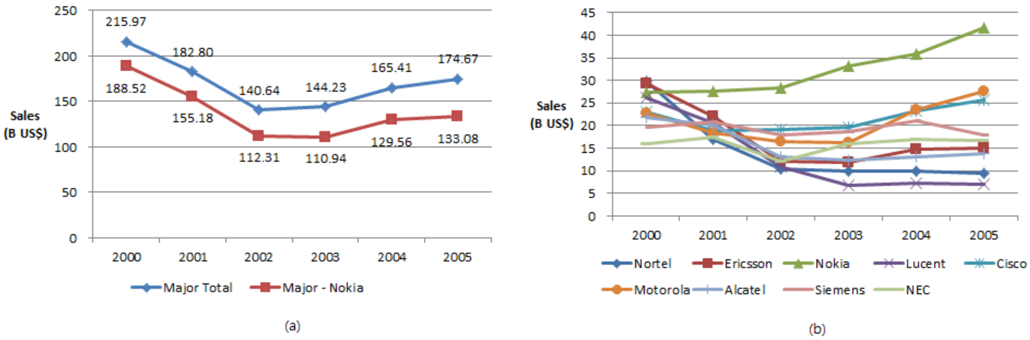


Figure 4.2 Total Sales (including handsets) of major telecommunications equipment vendors in the early 2000s

In order to survive this slowdown, major leaders in the market embarked on mergers and acquisitions beginning in the mid-2000s to achieve economies of scale. Alcatel, a 108-year-old French firm, and Lucent Technologies, a 137-year-old US firm, officially announced their merger in April 2006, establishing the merged company Alcatel-Lucent in December 2006. In June 2006, Nokia and Siemens agreed to launch a new joint venture by merging their telecommunications equipment arms, founding Nokia Siemens Networks (NSN) in April 2007. Moreover, Nortel Network which posted the highest sales in the world in 2000 at USD29.8 billion, filed for bankruptcy protection in January 2009, and sold off its LTE and CDMA business divisions to NSN in June 2009.

Specialization of each major vendor in the network equipment market

Each of the major vendors has strengths in different market segments. Ericsson and NSN are leaders in the wireless telecommunications system equipment market, while Cisco leads in the service provider routers and switches market and Alcatel-Lucent in the wire line telecommunications equipment market.

Ericsson ranked top in market share in the wireless telecom system equipment market in 1999 (based on shipments) with 27.6%, followed by Nokia with 17.6% and Motorola with 16.0%. Ericson also topped the industry in 2009 with sales of USD23.27 billion.

Nokia was number one in market share in the mobile handset sector (based on shipments) in 1999 with 26.4%, followed by Motorola with 17.6%). Alcatel ranked the first in the wire communications equipment market (with 16.6%, followed by Nortel with 12.5%, Lucent with 12.1% and Siemens with 11.2%). Nortel ranked top in the switching system market in 1999.

In 1999, Cisco had the largest market share in the network equipment market for service providers and firms which includes routers, VPNs, switches and wireless LAN (with 34.8%, followed by 3Com with 10.4%) and also in the remote land and internet access equipment market (with 12.2%, followed by 3Com with 11.2%, Motorola with 9.8% and Lucent with 9.1 percent).

Huawei's catch-up with Ericsson in sales

Figure 4.3 compares the annual sales trends of Huawei and Ericsson in the telecommunications equipment market including handsets.[21]

[21] Different sources have been used to analyze each year because the scope of the telecommunications equipment industry differs from one source to another. The network infrastructure market

Huawei manages its handset business division internally, but Ericsson spun off its mobile handset division in 2001 since has conducted the business through Sony Ericsson, a joint venture with Sony. The main reason for the drop in Ericsson's sales in 2001 was the downturn of the telecommunications equipment industry, but part of the reason can be attributed to the impact from the spin-off of its handset division.

According to Ericsson's 2000 annual report, consumer products (mobile handsets) accounted for 20.5% (SEK 56.3 million) of its total sales, and equipment systems accounted for 70.9% (SEK 194.1 million). Sales for equipment systems declined by 4% to SEK 187.8 million in 2001, and declined 30% to SEK 132.0 million in 2002.

Figure 3 indicates Ericsson's long-term sales trend of which peaked in 2000 and fell sharply through 2003. The figure shows a sharp decrease in sales, even after the spin-off of its mobile handset division in 2001 is taken into consideration. Figure 3 also shows a rebound in sales caused by the merger that the company conducted as part of its effort to turn around its declining sales.

excluding handsets can be divided into the carrier network infrastructure sector which accounts for 70% of sales (Gartner, 2011) and the enterprise network infrastructure sector. Again, the carrier network infrastructure sector may be divided into the service provider routers and switches sector and the mobile carrier network infrastructure sector. Therefore, each source randomly defines the scope of analysis based on its needs, which leads to a difference in sales figures. Moreover, Huawei does not release any sales data other than its annual report published on its official website, as it is not a publicly held company. Thus, we had to rely on a variety of sources.

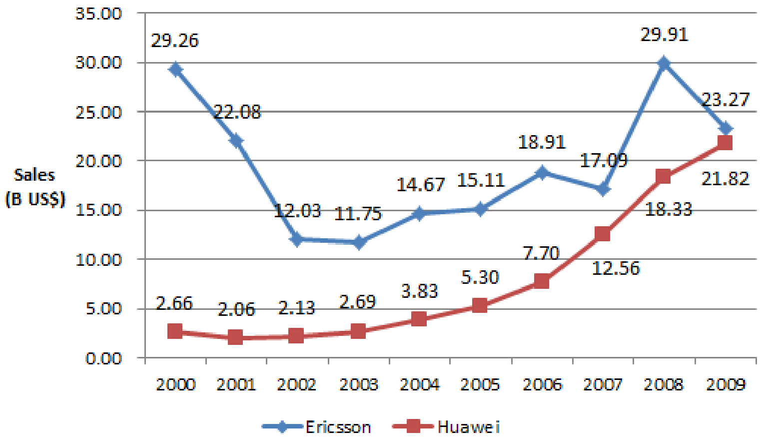


Figure 4.3 Sales of Ericsson and Huawei in telecommunications equipment market (including handsets)

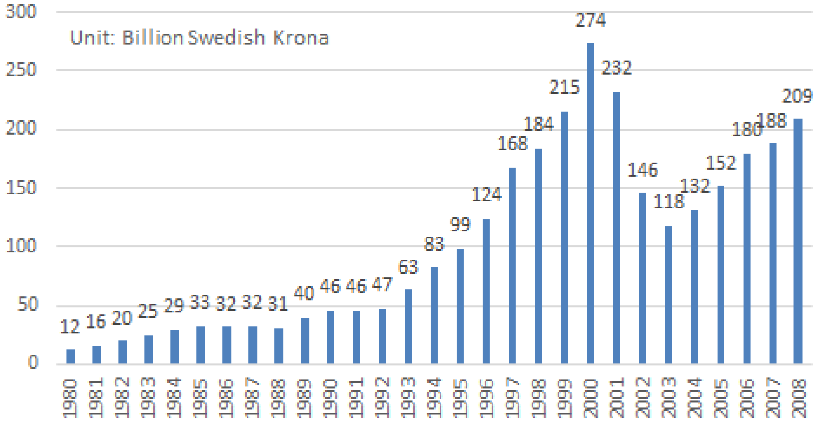


Figure 4.4 Sales of Ericsson

Huawei is one of the very few vendors that saw an increase in sales amid the severe slowdown of the industry in the early 2000s. Figure 4.4 indicates that while Ericsson witnessed its sales drop by almost one-third over the three years from 2000 to 2002, Huawei's sales did not decrease during the same period. Huawei rather posted a sharp increase in sales after 2003 and almost caught up with Ericsson in sales in 2009

3)-3 Patent data analysis of Huawei and Ericsson

3.1 Making sense of the comparison

The technological proximity of Huawei and Ericsson at the IPC subclass level stands at 0.912.[22] On these grounds, it can be said that an analysis of Huawei and Ericsson at the technological level is very meaningful.

Firm	WIPO CODE	2000	2001	2002	2003	2004	2005
Ericsson	26	29.9	27.6	16.9	14.2	16.4	10.0
Ericsson	27	40.0	73.9	43.6	26.5	20.9	31.1
Ericsson	28	20.1	24.4	10.6	2.6	6.7	7.7
Ericsson	30	85.9	59.1	35.6	24.2	32.8	21.1
Ericsson	31	683.3	575.1	494.4	345.5	443.4	452.6
Ericsson	total	870	766	605	414	521	523

Firm	WIPO CODE	2006	2007	2008	2009	2010	**share**
Ericsson	26	15.4	8.5	4.8			**3%**
Ericsson	27	35.2	42.3	35.2	2.0	2.0	**7%**
Ericsson	28	3.8	8.9	10.8			**2%**
Ericsson	30	31.9	19.2	2.5	1.0		**6%**
Ericsson	31	530.0	577.3	324.8	13.0		**83%**
Ericsson	total	618	658	378	16	2	**100%**

22 This level of technological proximity can be considered very high and may suggests that two firms are competing with each other, considering that technological proximity between Samsung and Sony, two major competitors in the global electronics industry was 0.98 (Joo and Lee, 2010).

Firm	WIPO CODE	2000	2001	2002	2003	2004	2005
Huawei	26		0.8	0.4	0.3	0.8	0.3
Huawei	27		0.5	1.4	1.1	1.3	1.7
Huawei	28		0.5				0.7
Huawei	30				0.3	1.0	0.5
Huawei	31	3.0	26.3	35.2	60.3	82.0	215.0
Huawei	total	3.0	28.0	37.0	62.0	85.0	219.0

Firm	WIPO CODE	2006	2007	2008	2009	2010	**share**
Huawei	26		4.1	1.0	1.2		**0%**
Huawei	27	17.6	24.6	29.5	3.5	1.0	**3%**
Huawei	28	2.2	4.3	25.2	2.0	0.7	**1%**
Huawei	30	4.4	8.8	9.7	1.2		**1%**
Huawei	31	538.9	605.4	561.6	81.7	1.3	**94%**
Huawei	total	563.0	647.0	627.0	90.0	3.0	**100%**

Table 4.3 Ratio of five major fields of technology of Huawei and Ericsson according to Wipo

The degree of technological overlap between Huawei and Ericson was measured by the common citation rate suggested by Mowery et al. (1998) and can be an alternative measure to assess the degree of technological competition between two firms.

$$\text{common citation rate}_{ij} = \frac{\text{citation in firm i's patents to patents cited in (or citing) firm j's patents}}{\text{total citations in firm i's patents}} + \frac{\text{citation in firm j's patents to patents cited in (or citing) firm i's patents}}{\text{total citations in firm j's patents}}.$$

The technological overlap between two firms measures the share of citations directed to the same patent by each of the firm's own patents among each firm's total citations made or the number of citations received by the same patent among each firm's total received citations.

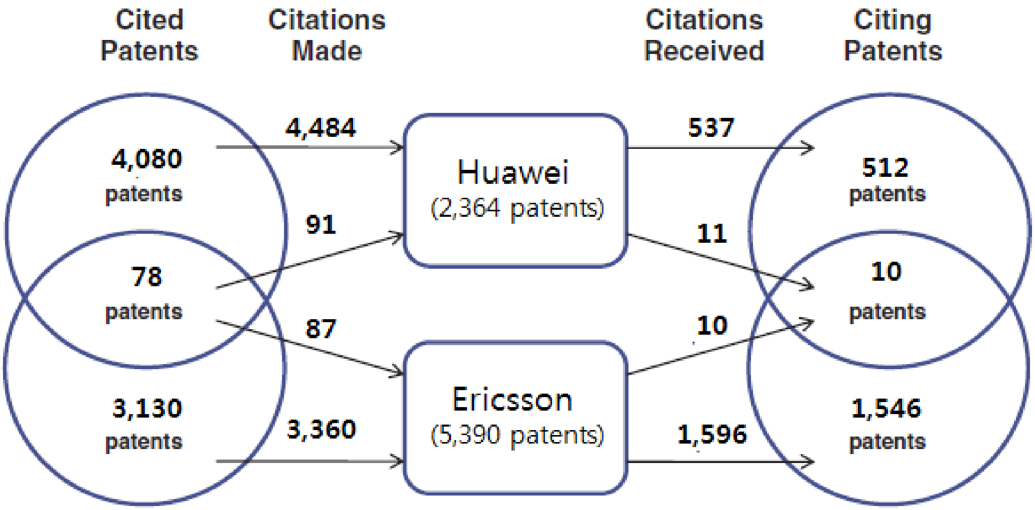


Figure 4.5 Technological overlap between Huawei and Ericsson

The common citation rate measured by citations made is 0.045, and by citation received is 0.026. Considering such a rapid catch-up of Huawei rapid catch-up in terms of the number of patents filed, this common citation rate is not lower than average.
[23]

However, the number of patents filed by Huawei as of the first half of the 2000s was so small – (for instance, it had only three EPO patents in

[23] According to Mowery et al. (1998) the average common citation rate between two randomly selected firms was between 0.01464 and 0.02413. The average common citation rate between pharmaceutical and biotechnology firms in in-vivo human therapeutics, which is a very narrow area, was 0.0254 according to Rothaermel and Boeker(2008).

2000, while Ericsson had 871) - that the measured value is not meaningful.

As we were able to observe meaningful result in the degree of technological proximity between Huawei and Ericsson, the technological characteristics of Ericsson and Huawei would be compared and analyzed using their patent portfolios. The followings is a comparison of the two firms' patents in terms of quantity.

3.2 Catch-up in terms of the quantity of patents

As presented above, Huawei almost caught up with Ericsson in the number of European patents in 2007 and began to surpass Ericsson by a large margin in 2008, Huawei also began to surpass Ericsson in the number of US patents in 2007.

Table 4.4 indicates the number of PCT patent filings, in which Huawei began to overtake Ericsson in 2006. Some firms tend to file a patent through the PCT before filing a patent with the national patent offices of various countries individually to simplify the process of patent registration. PCT filing statistics show that Huawei is one such firm that actively utilize PCT.[24]

[24] Even if although patents is filed with the PCT, the applicant must also apply for patents in each national authority to get their patents properly registered. In addition, firms may not use the PCT at all to apply for a patent. By analyzing the individual patent filed with each national patent office, one can analyze all the patents filed to that patent office. Therefore, it is better to compare the two companies' European patents than PCT patents only.

Table 4.4 Number of PCT patent filings

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Huawei	8	30	83	111	176	425	1178	1545	1869	1499	39	6963
Ericsson	1123	1109	796	478	564	561	723	888	1323	516	16	8097

Number of patent filings by country and year

Company	CTRY	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Huawei	EP	3	28	37	62	85	219	563	647	627	90	3	2364
Ericsson	EP	871	766	606	431	521	523	618	658	378	16	2	5390

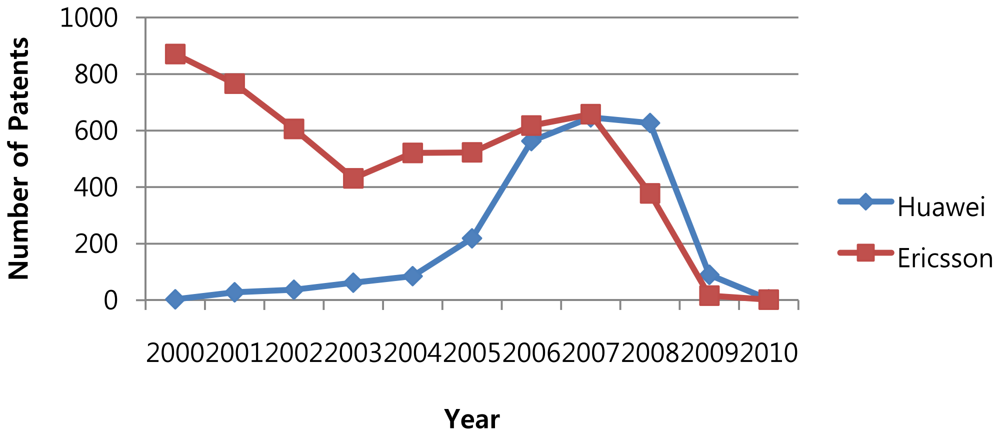
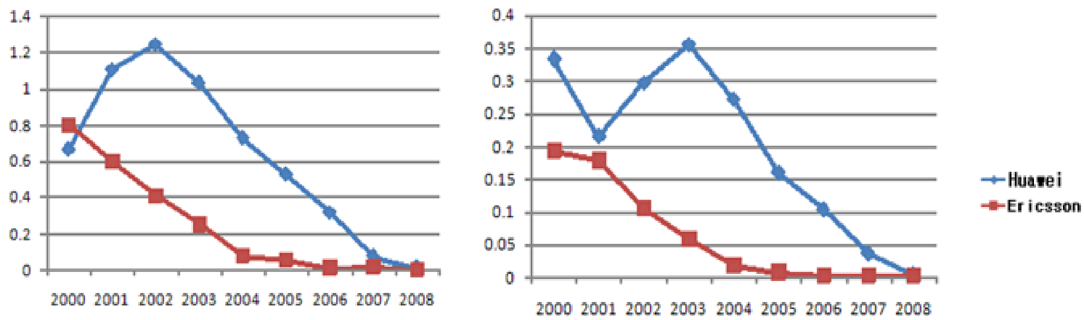


Figure 4.6 Number of patents filed by Huawei and Ericsson

3.3 Catch-up in terms of the quality of patents

Table 4.5 Average number of citations received by European patents held by Huawei and Ericsson

	Total number of citations received		Number of citations received by EP patents	
	Huawei	Ericsson	Huawei	Ericsson
2000	0.667	0.805	0.333	0.193
2001	1.107	0.603	0.214	0.179
2002	1.243	0.408	0.297	0.106
2003	1.032	0.251	0.355	0.058
2004	0.729	0.079	0.271	0.019
2005	0.521	0.054	0.160	0.008
2006	0.313	0.013	0.103	0.003
2007	0.073	0.015	0.036	0.003
2008	0.010	0.003	0.003	0.003



(a) All patents in PATSTAT (b) EP patents only

Figure 4.7 Average number of citations received by patents held by Huawei and Ericsson

As explained above, we compared the two firms' patents based on their European patent information, because both companies filed more patents with the EPO than they did with the US patent office. The total number of citations takes into account the citations of all patents in the PATSTAT database for instance, it includes Huawei and Ericsson's US patents which cited their patents filed with the EPO. On the other hand, the number of citations received by the two firms' EPO patents includes only the citations of European patents.

As indicated in Figure 6, Huawei started to overtake Ericsson in the average number of citations in 2001. Notably, Huawei only filed its first patent with the EPO in 2000.

This is a very interesting finding, particularly when compared to Joo and Lee (2010) analysis of Samsung's dramatic catch-up with Sony.

Samsung surpassed Sony in sales for the first time in 2005, although it had already surpassed Sony did in terms of market capitalization in 2002. Samsung had already overtaken Sony in the early 1990s in terms of quality and has maintained its lead ever since. In addition, Samsung had already caught up with Sony in terms of quality before it did so in sales. However, it can also be said that Samsung made continuous efforts in terms of quality of patents for decades.

However, Huawei's catch-up with Ericsson in terms of quality demonstrates a slightly different pattern. Huawei filed its first European patents in 2000, but it started to outdo Ericsson in the total number of citations in the following year and has remained ahead ever since. This can be interpreted to mean that the quality of Huawei's patents was very high from the beginning and that the high quality has been maintained.

In terms of quantity of patents, Huawei began to catch up with Ericsson for the first time in 2008. However it may be premature to generalize, that the same pattern seen in Samsung's catch-up with Sony - it overtook Sony, that in quality before it did so in quantity, applies to the case of Huawei and Ericsson as well. However, what is notable in Huawei's case is that it was in the lead compared with Ericsson in terms of quality from the time it first started to file patents.

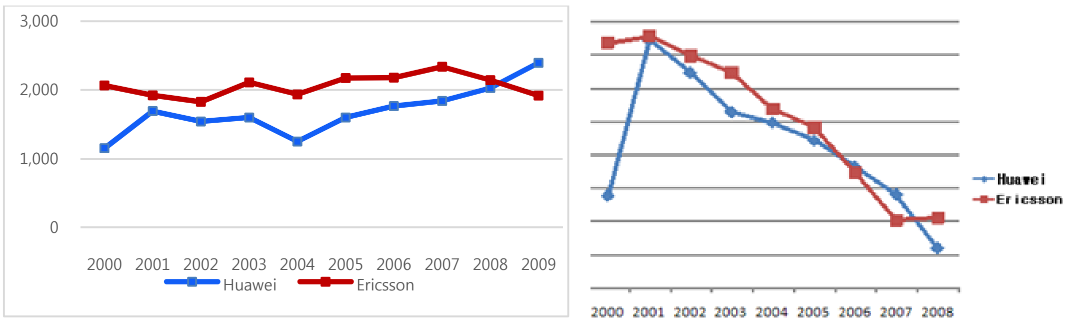
This can be interpreted to mean that Huawei filed patents of higher quality than Ericsson's from the beginning, and continued to do so thereafter, or that Ericsson's low-quality patents outnumbered its high-quality patents.

In short, it can be said that Huawei began to overtake Ericsson in terms of patent quantity in the late 2000s (in terms of the number of patent filings in 2007, and in terms of the number of registered patents in 2006). In terms of quality, or the number of citations received by their patents, Huawei began to overtake Ericsson in the early 2000s.

It is hard to say, though, that this is a "very direct" indication that the quality of Huawei's patents is higher than Ericsson's because the number of its patents was relatively small in the early 2000s. However judging from the trend shown afterwards, it is likely safe to say that the quality of patents filed by Huawei is very high. It is also possible that Ericsson filed and registered a large number of low-quality patents as well as many high-quality patents, which leads to the higher average number of citations received by Huawei's patents. However, as discussed above, it is fair to say that the quality of Huawei's patents was high, as this trend continued even after the mid-2000s.

That Huawei's successful catch-up in technological quality took place before its catch-up in quantity is the same as the case of Samsung Electronics and Sony as studied by Joo and Lee (2010).

3.4 Forward and Backward citation lag



(a) Backward Citation Lag (b) Forward Citation Lag

Figure 4.8 backward and forward citation lag

According to Figure4.8 Huawei began outdoing Ericsson in 2000 when it started to file its own patents. This means that Huawei cited more recent patents than Ericsson did from the time that it started to file European patents. This indicator can be interpreted mean as that Huawei developed its own technologies based on the most recent technologies from the initial stage, at least from 2000, rather than referring to existing technologies. Such a phenomenon may also be closely related to the fact that Huawei began to surpass Ericsson from early on in terms of quality. The results of the forward citation lag analysis shows that Ericsson's patents were cited more quickly than Huawei's by other patents, except for during 2006 and 2007.

3.5 Level of technological dependence

The level of technological dependence is reflected in the citation patterns between the catch-up firm and the leading firm. Since 2008, the trend shows that Huawei has become increasingly independent from Ericsson.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Ericson	0.00%	0.00%	0.00%	0.00%	0.00%	2,13%	0.00%	3.39%	0.00%	0.00%
Huawei	0.00%	4.17%	8.33%	7.50%	6.96%	7.07%	6.77%	8.39%	8.11%	0.00%

Table 4.6 %of citations directed at the counterpart firm's patents out of total citations.

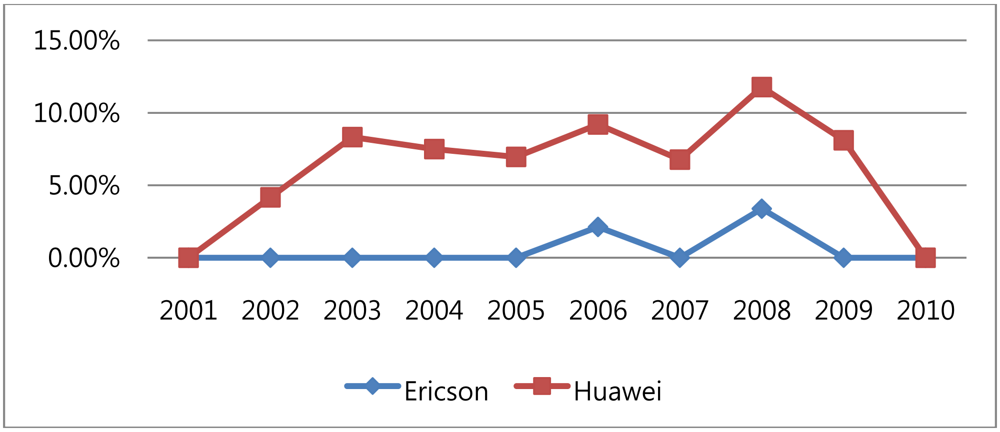


Figure 4.9 The share of citations directed at the counterpart firm's patents

3.6 Self-citation ratio

The self-citation ratio is an indicator of a firm's ability to protect it's own innovations from being copied by others, thus monopolizing any profits from the innovations. The lower the self-citation ratio is, the higher the vulnerability of the designs to being copied, and thus the lower the profits that can be reaped from the innovation. The self-citation ratio can be measured by the proportion of self-citations out of total citations (Trajtenberg et al., 1997).

Self- Citation Ratio of Huawei and Ericsson

	Huawei	Ericsson
2000	0.00%	11.20%
2001	0.00%	11.80%
2002	0.00%	13.30%
2003	0.70%	16.50%
2004	1.60%	11.10%
2005	4.30%	13.10%
2006	3.10%	6.60%
2007	3.20%	12.20%
2008	6.90%	6.50%
2009	7.50%	18.20%

Table 4.7
Self Citation Ratio of Huawi and Ericsson

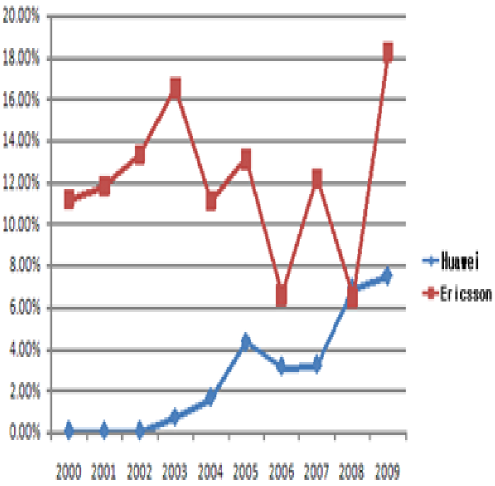


Figure 4.10
Self Citation Ratio of Huawi and Ericsson

As Huawei only started to file patents relatively recently, it often cited patents of other firms in the early 2000s. However, its self-citation ratio steadily increased starting from 2003, which is well indicated in Figure 4.10

3.7 Citation of non-patent literature as science-base

As presented before, Huawei's catch-up in quality demonstrates a unique pattern different from other common catch-up patterns. In terms of total number of citations, Huawei began overtaking Ericsson the year after it filed its first patents in 2000 and has maintained its lead ever since. We have already pointed out that this may be interpreted as evidence that the quality of Huawei's patents was very good from the start, or that Ericsson's low-quality patents outnumbered its high-quality patents. An analysis of "originality" and "citations in non-patent" can help explain this pattern.

Huawei cited more non-patent literature (most begin scientific papers in academic journals), than Ericsson did. As Figure 9 indicates, Huawei started to overtake Ericsson from 2000 when it filed its first European patent. However, the figures dropped sharply more recently, which might represent a truncation problem.[25]

China has traditionally been strong in the basic science. Although the country does not stand out in the field of application technology, such as high-definition flat televisions or smart phones, it excels in basic science, such as space sciences, physics and chemistry. The effects of Huawei's strong science base on its catch-up are still a matter of conjecture.

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[25] It takes a few years for an applied patent to be granted, and made available to the public (and th researchers). Moreover, it takes years for a patent to be cited by following patents, because inventors of following patents can only be aware of the patent after it is available to the public. Finally, it takes a few years more for the citing patents to be granted and made available to the public (and researchers).

	Huawei	Ericsson
2000	4.00	1.01
2001	1.75	1.08
2002	2.05	1.07
2003	2.24	1.07
2004	2.28	1.07
2005	2.25	1.02
2006	2.03	1.11
2007	1.89	1.06
2008	1.59	1.10
2009	0.92	1.56

Table 4.8 Average Number of Citations to Non-Patent Literature

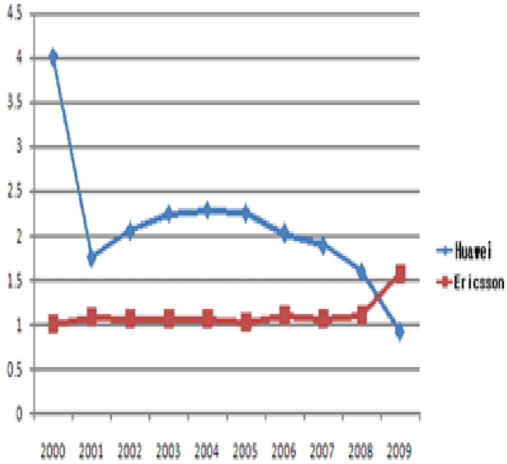

Figure 4.11 Average Number of Citations to Non-Patent Literature

2. Hyundai Motor's Catch-up with Mitsubishi

1) Introduction

Overcoming their early technological lag behind established car makers, automobile manufacturers in Korea have become the first car makers, from among the world's developing countries, to develop and launch their own independent engines and models successfully in the international market. This makes it reasonable to say that the history of Hyundai Motors is that of the Korean automobile industry.

The Korean automobile industry has made great strides since it first started in 1962. In 1980, the total output of automobiles in from Korea was too small to be expressed in the world automobile chart, equaling only about one tenth of that of Brazil, the 10th -ranked country in the world. However, the nation's auto industry continued to grow and reached 11th in the world in 1986 and 5th in 1994.[26]

Hyundai Motor Company started in 1967 and produced about 4,000 units of automobiles in 1970. In 1994, when the Korea automobile industry ranked 5th in the world, Hyundai Motors' output topped one million units, and accounted for 49% of Korea's total output.[27] This figure shows that there was a wide gap between Hyundai Motors and the second and the third largest car makers in Korea, Kia Motors and Daewoo Motors.

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[26] Korea Automobile Manufacture Association

[27] Ibid.

Later, Hyundai Motors continued to grow in its economy of scale by merging with Kia Motors in 1998. Hyundai Motors now exerts a competitive edge comparable to that of Japanese automobile manufacturers in advanced markets such as the United States and Europe as well as in emerging markets such as China, Russia, and India due to the an upswing in exports despite lagging sales in the domestic market. Hyundai Motors, ranked 5th in the world in sales revenue in the first half of 2013, following Toyota, GM, Volkswagen, and Renault Nissan.

It will be very interesting to analyze how in just 40 years Hyundai Motors, a small car maker in developing country, which lacked technological capacities, marketing ability, and brand awareness in its early stages, has been able to catch up with leading automobile manufacturers with an almost 100-year history and tradition in the automobile sector in developed countries. This study analyzes the success of Hyundai Motor Company in terms of technology through patent data analysis.

2) Literature Review

The automobile manufacture industry is scale-intensive and less reliable in terms of science than the electronics industry (Pavitt, 1984). The automobile manufacture industry has a more predictable innovation process and less frequency of conceptual change. In addition, tacit knowledge in the automobile manufacture industry is more important in knowledge base than in other sectors.[28]

Lim & Lee (2001) analyzed the factors that lead to the development of Hyundai Motor Company (hereafter, Hyundai) in terms of the sectoral characteristics of the automobile industry. This paper focuses on the fact that Hyundai has succeeded in the global market by inventing its own independent engine and fuel injection system through a huge investment in technology and an in-house research and development (R&D) center. The accumulation of technological capacity makes it possible to catch up with the leading manufacturers. This paper emphasizes that the process to invent a new engine of its own was noticeable when Hyundai invented an electronic injection-based engine. The invention is a new trend of engine technology that skipped the re-creation of a carburetor-based engine, the standard model at that time. This process is classified as a stage skipping catch-up.

The concepts of imitation and innovation deal with the history of Hyundai and the process to acquire the needed technologies (see chapter 5 for details) (Kim, 1998). The concepts give a detailed account of the innovation process through which Hyundai had its own

[28] Economics of East Asia and Technological Catch-up, 2007

automobile model leapfrog the early imitation stage of a small automobile assembly plant. The concept also deals with the learning process of new technologies in the imitation stage and the creative innovation process of inventing its own technologies.

There are several papers that deal with the technological developments of Hyundai in terms of organizational learning (Sim, 2005), production method (Cho, 1992), and business strategy (Cho, 1993).

3) Hyundai Motors catch-up with Mitsubishi Motors in the automobile industry

3)-1 A brief introduction to Hyundai Motors and Mitsubishi Motors (A History of Hyundai Motor Company and Mitsubishi Motors: Why do we compare together).

Hyundai Motor Company (hereafter, Hyundai) developed its own independent model of a compact car. Hyundai exported the compact cars in bulk to the world market, which is an exceptional accomplishment for an automobile company within a developing country. Hyundai had its own independent automobile development system since the establishment of the Namyang R&D center. Hyundai has been equipped with the world's top ten cutting-edge automobile research facilities since April 1994. Hyundai has strived to develop its own technology without a dependence on multinational car makers. A variety of car models of Hyundai has demonstrated this well. The *Pony* was the first independent compact car model. The *Excel* accomplished a high degree of technological independence as a full-blown export car model. The *Accent* was the first car model designed in 1994, from which almost 100% independence of technology in important parts such as the engine.[29]

However, Hyundai hungered for technology as a subcontractor of Ford Motor Company (hereafter, Ford) in its early stages. Hyundai has secured many alliances with Mitsubishi Motors (hereafter, Mitsubishi) because Mitsubishi did not require stock shares and management rights like Ford and other multinational car makers. In 1973, Hyundai secured a technical

[29] Korea Automobile Manufacture Association

partnership with Mitsubishi for the manufacture of gasoline engines, accelerators, and rear axles. Hyundai also organized a research team to computerize the design process of automobiles in 1973. The research team conducted an in-depth study to operate the CAD/CAM system of Mitsubishi. Hyundai strengthened the partnership with Mitsubishi with the development of *Excel*, and secured a technical alliance for the engine, transaxle, car body, and emission control technology. Hyundai sent engineers to Japan for training.

In return for the technology transfer, Hyundai gave ten percent of its stock shares to Mitsubishi. The percentage rose to twelve percent. The greatest concern for Hyundai, which strived for the acquisition of technology by giving up some of their stock shares, was the development of the compact car model, *Excel*. The *Excel* model was planned for export to the United States if they met the regulations of the US auto market. One regulation was to equip *Excel* with an automobile exhaust purification system. The fact that Hyundai gave up ten percent of its stock shares to Mitsubishi indicates how desperate Hyundai was for this technology. The *Pony* was an older model that could not be exported to the US auto market because it failed to satisfy auto exhaust regulations.

In addition, the designs of all former models that preceded the *Accent* were based on the designs of Mitsubishi. Half of the twenty-two cases of technological alliances with Japan were with Mitsubishi, which shows the strong partnership for a considerable period early on between Hyundai and Mitsubishi.

The partnership between Hyundai and Mitsubishi makes it meaningful and interesting to compare the two companies. Mitsubishi has provided a considerable amount of technological assistance to Hyundai for a considerable period of time.

3)-2 Hyundai's Catch-up in the Market

Hyundai made the technical alliance with Mitsubishi in 1981 by giving up ten percent of their stock shares. The sales of Hyundai in 1990 were very low to be shown in the graph that compared sales to Mitsubishi.

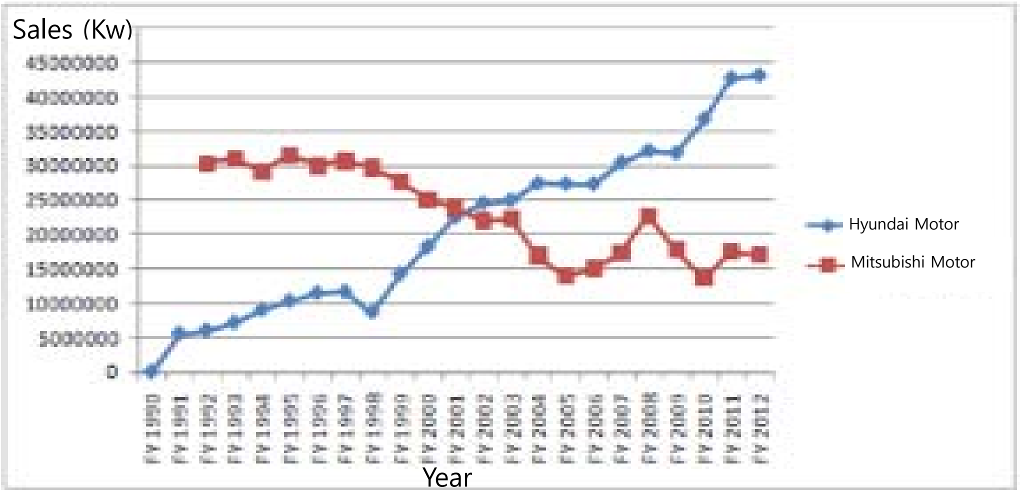

Figure 4.12 Sales of Hyundai Motor and Mitsubishi[30]

Afterwards, the sales revenue of Hyundai continued to grow rapidly due to the export of the *Excel*. The *Excel* achieved relative success in the US market in 1994, which amounted to one third of Mitsubishi's sales. The

[30] http://www.bloomberg.com/markets/

Accent was designed by Hyundai and was introduced to the market in 1995 when the upgraded Namyang R&D center opened.

The growth of Hyundai's sales revenue stagnated due to the International Monetary Fund (IMF) financial crisis of 1998. However, Hyundai restarted the quantum leap with economy of scale through a merger with Kia Motors (hereafter, Kia). Finally, Hyundai surpassed Mitsubishi and continued to widen the gap in 2002. In addition, the sales revenue of Hyundai more than doubled that of Mitsubishi in 2012.

Hyundai struggled to acquire the needed technology from Mitsubishi only thirty years ago. Presently, Hyundai has shown dramatic success by accomplishing more than two and one-half times the sales revenue than Mitsubishi. However, Mitsubishi has struggled with automobile sales since 2000.

3)-3 Patent data analysis of Hyundai and Mitsubishi

We analyzed in qualitative and quantitative terms when and how Hyundai overtook Mitsubishi. The analysis is based on the patents registered at the United States Patent and Trademark Office (USPTO). For the analysis, we used information about the invention patents of Hyundai and Mitsubishi that were registered from 1989 to 2003 at the USPTO. For the analysis of the citations, we used the database of the American patents constructed by Hall and the database at the US National Bureau of Economic Research (NBER).

We investigated the numbers and citations of registered patents to analyze the technological catch-up in quantitative and quantitative terms. We compared the backward citation lag that represents how recent the patents are cited by their patents. We also investigated how fast they were acquired and recreated with up-to-date technologies in the process of technological overtaking. In addition, we compared the frequency for citing basic science related patents from the patent data of Hyundai and Mitsubishi. We anticipate that this will reveal their knowledge base characteristics.

Finally, we drew a conclusion using the EPO Worldwide Patent Statistical Database (PATSTAT) because the data from NBER do not provide information related with non-patent literature.

3.1 Catch-Up in terms of the quantity of patent

We examined the number of registered patents per year to conduct a quantitative analysis of the technological overtaking of Hyundai and Mitsubishi.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	2	1	5	7	24	29	90	104	111	31	99	144	98	106	14
MITSUBISHI	38	30	42	41	61	44	44	41	77	44	15	29	24	29	19

Table 4.9 Number of patents held by Hyundai and Mitsubishi

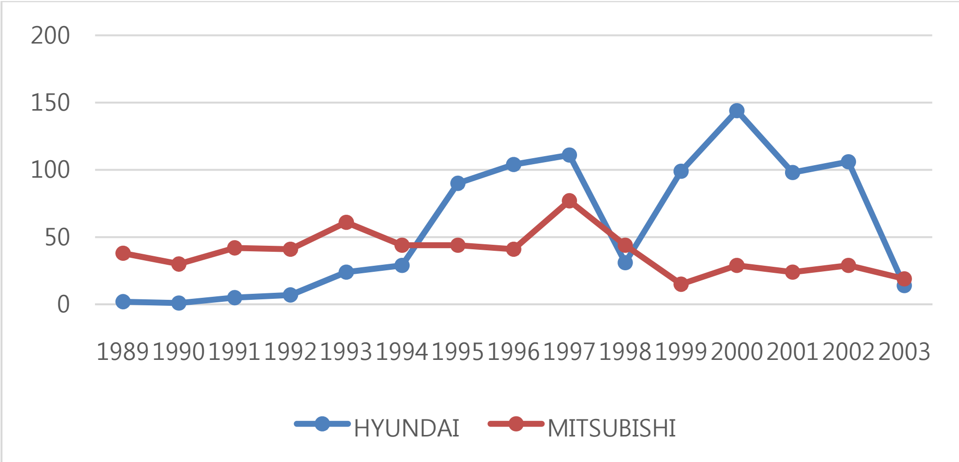

Figure 4.13 Number of patents held by Hyundai and Mitsubishi

Figure above shows a trend for the number of patents of Hyundai and Mitsubishi. Hyundai filed their first two patents in 1989 and filed more patents than Mitsubishi since 1995. Hyundai has outcompeted Mitsubishi in patents by filing more than one hundred patents per year.

Hyundai invested a large sum of economic capital in technology during the early 1990s. Hyundai also invested a large sum of human capital since establishing the Namyang R&D center in 1995, which laid the foundation for the catch-up in 2002. Hyundai craved for their own independent technologies through the early stages in the 1970s and the technological partnership stage in the 1980s.

The number of patents by Hyundai decreased in 1998 due to the influences of a steep plunge in domestic demand and the low investment in R&D caused by the IMF financial crisis in 1998. Quantitatively, the point of technological catch-up of Hyundai with Mitsubishi precedes the sales revenues catch-up of Hyundai to Mitsubishi.

3.2 Catch-Up in terms of the quality of patent

We conducted a qualitative study for patent citations to analyze the technological catch-up of Hyundai with Mitsubishi. Many studies show that the frequency of a cited patent in other patents represents the patent's high technological value. Figure below compares the frequency of Hyundai and Mitsubishi patents cited by Hyundai and Mitsubishi.

	1989	1990	1991	1992	1993	1994	1995
HYUNDAI	5.0000	3.0000	4.8000	4.7143	4.5000	2.1379	3.4333
MITSUBISHI	9.0526	9.4667	11.6905	8.5854	9.4098	11.5000	14.3182

	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	2.8462	2.3063	2.3871	1.9899	2.1597	0.9898	0.5660	0.7143
MITSUBISHI	10.9512	9.6234	8.3636	8.2667	3.5517	4.3333	2.3103	1.2632

Table 4.10 Average citations received by Hyundai Motor and Mitsubishi's patents

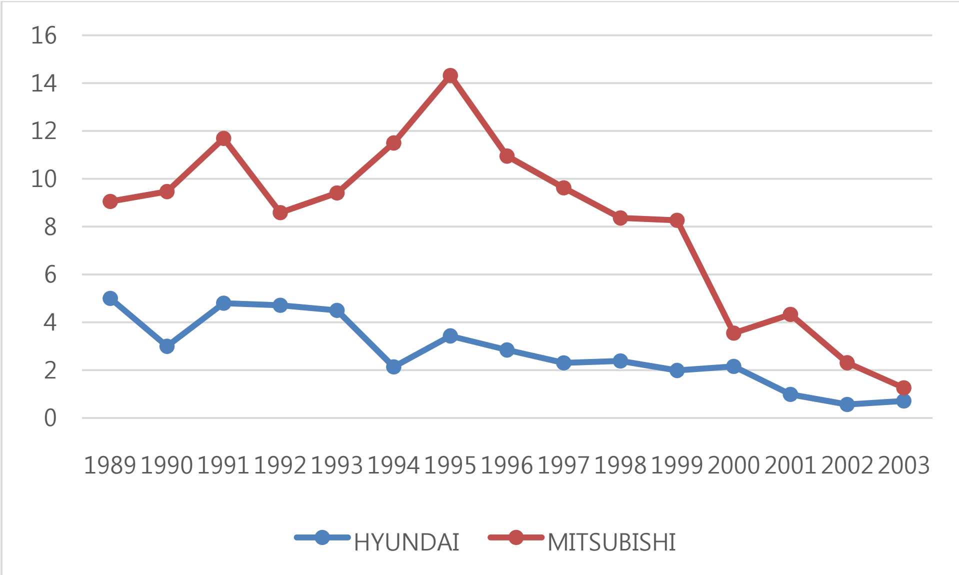

Figure4.14 Average citations received by Hyundai Motor and Mitsubishi's patents[31]

An analysis for the average number of received citations at the firm level shows that the higher frequency of Mitsubishi patents cited throughout the whole period.

[31] Overall decreasing trend of average received citations shows that the citation-based quality measures reflect not only the quality of the patents but also the opportunity of the patents being cited. Older patents have more opportunities to be cited than newer patents. In spite of the limitation, considering the patents of both firms had the same opportunities to be cited, the truncation problem can be partly mitigated by analyzing the ratio.(Joo & Lee 2009)

3.3 Backward citation lag

An analysis of backward citation lag shows how quickly a patent can cite up-to-date patents and demonstrates how quickly a corporation acquires and recreates cutting-edge technologies during the technological overtaking process.

An analysis of backward citation lag at the firm level shows in Figure _ that except for 1989 and 1990, when Hyundai filed one or two patents, Mitsubishi led Hyundai in patents.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	4.3333	4.0000	7.5540	5.5108	6.5796	6.5658	7.0600	7.8868	7.7753	6.6437	7.4192	8.1384	8.7203	10.1855	10.0228
MITSUBISHI	5.1146	5.3119	4.6820	5.1596	5.6389	5.4118	6.3506	5.6120	5.9068	6.1863	6.2202	5.9285	5.3310	7.3125	8.4351

Table 4.11 the backward citation lag of Hyundai Motor and Mitsubishi’s patents

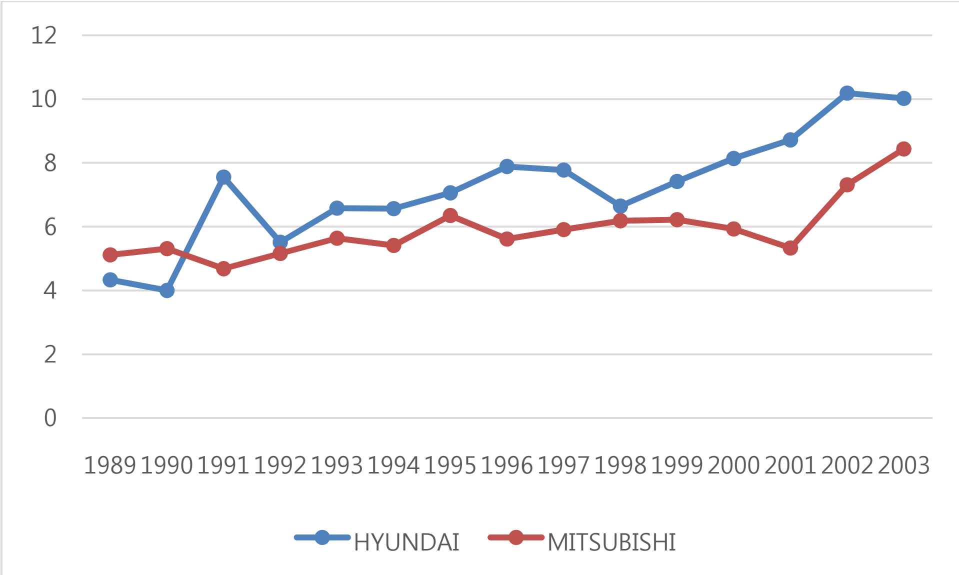

Figure 4.15 the backward citation lag of Hyundai Motor and Mitsubishi's patents

For a more in-depth analysis, we need to examine various technologies section by section. The examination of a sub-technology within each section reveals which sections Hyundai and Mitsubishi are using more up-to-date technologies.

The five subsections of the technologies are identical (Table). The number in the bracket indicates the code number of the sub-section by IPC and the result of the analysis in each section is as follows.

The five subsections are: transport/packaging (10), engine/pump (22), mechanical components (23), measurement/optics (26), and computers (27).

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	2.0000	4.0000	4.0238	5.0808	6.0429	6.8444	7.4304	8.5758	7.7556	4.8476	7.8428	8.3018	9.3453	10.5170	5.0952
MITSUBISHI	4.4240	5.8177	4.0618	4.8583	5.7013	5.3008	8.0468	5.8191	5.8322	3.8769	7.2458	7.6474	6.7281	8.3341	8.8429

Table 4.12 The backward citation lag of Hyundai Motor and Mitsubishi's patents in transport/packaging(10)

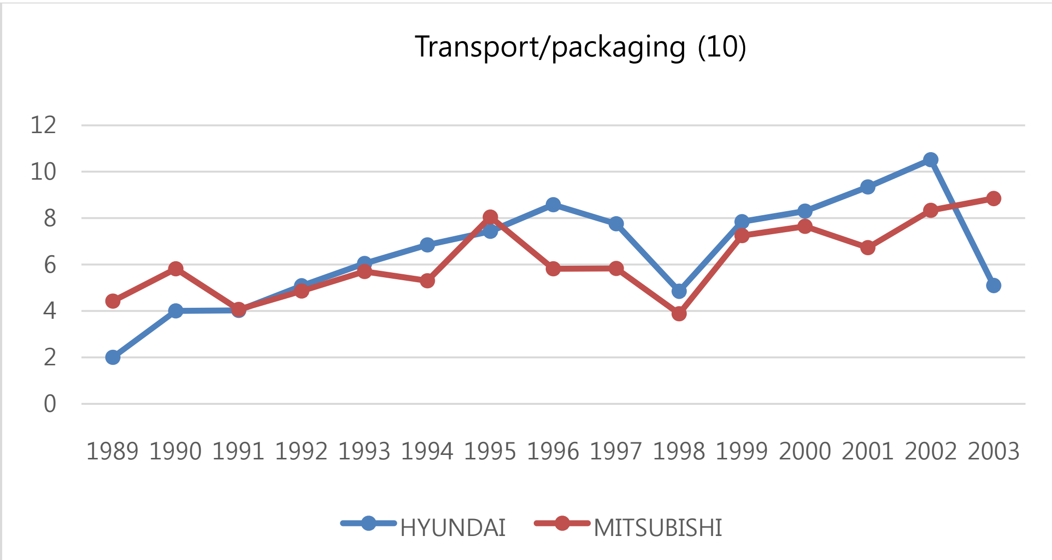

Figure 4.16 The backward citation lag of Hyundai Motor and Mitsubishi's Patents in transport/packaging(10)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI			8.1111	5.0000	7.4167	7.8886	7.2485	8.6169	8.6717	7.8286	7.0378	7.0556	9.8197	10.4589	10.5633
MITSUBISHI	6.0162	5.2837	4.5195	6.2067	5.6586	5.6421	5.5860	5.1135	5.4278	5.7834	5.8875	4.7688	4.7321	5.7580	8.9857

Table 4.13 The backward citation lag of Hyundai Motor and Mitsubishi's patents in engine/pump(22)

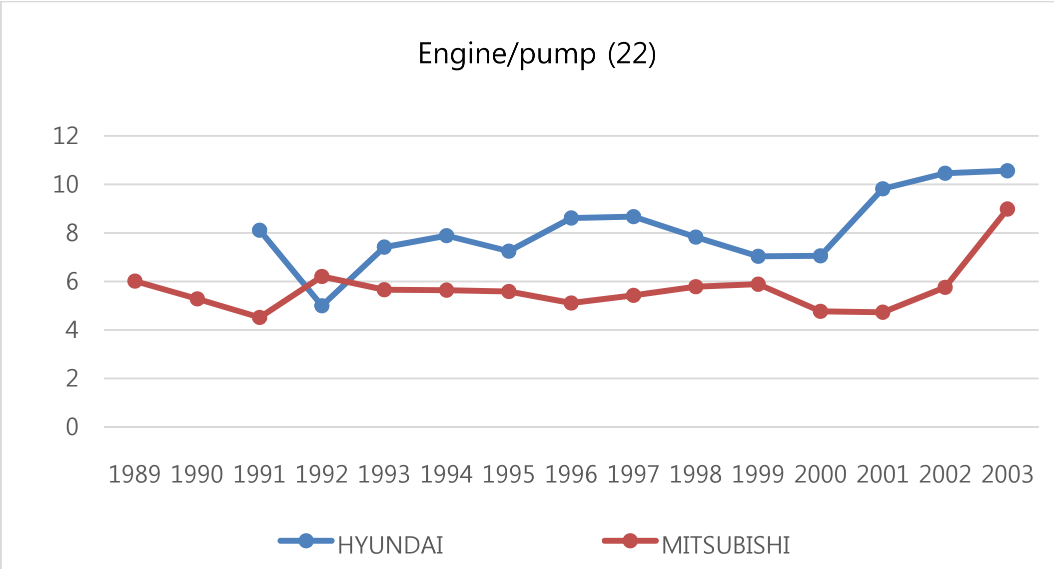

Figure 4.17 The backward citation lag of Hyundai Motor and Mitsubishi's patents in engine/pump(22)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	6.6667			4.5000	5.5833	5.2104	6.0474	6.5916	8.2187	6.1715	7.8475	7.5829	7.5155	8.4343	7.0000
MITSUBISHI	6.3333		7.0000	2.5833	5.7761	4.8786	5.0161	7.8889	4.7178	8.1186		6.5444		6.8571	

Table 4.14 The backward citation lag of Hyundai Motor and Mitsubishi's patents in mechanical components (23)

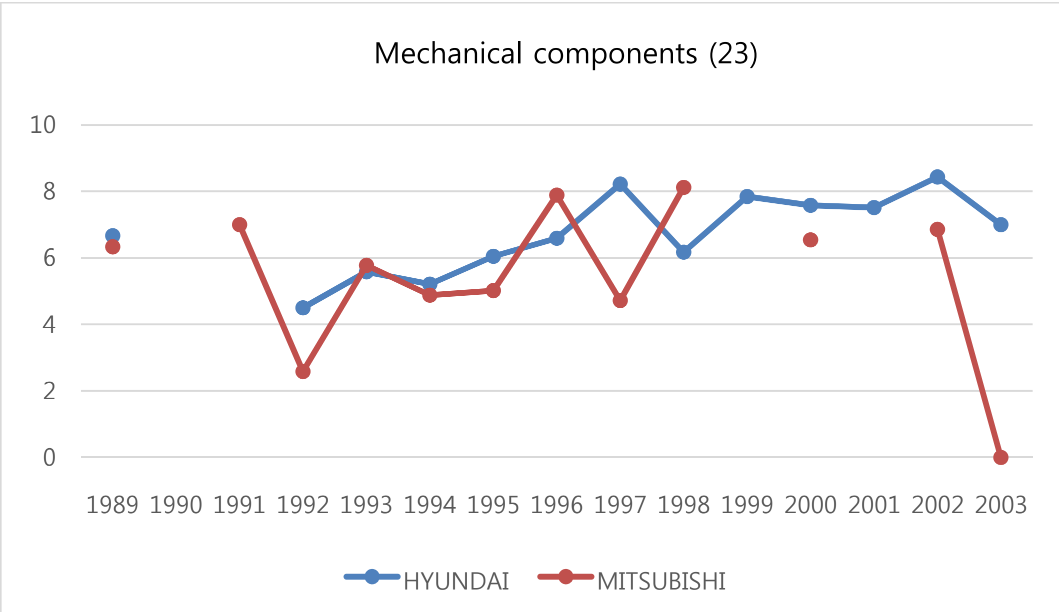

Figure 4.18 The backward citation lag of Hyundai Motor and Mitsubishi's patents in mechanical components (23)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI							7.4000	5.9876	7.1518	5.3333	4.9184	7.3750	12.5111	11.0896	8.6000
MITSUBISHI	4.5238	5.3750	9.4312		3.9072	4.5799	5.1538	5.1806	9.4434			7.1518		8.0000	5.0000

Table 4.15 The backward citation lag of Hyundai Motor and Mitsubishi's patents in measurement/optics(26)

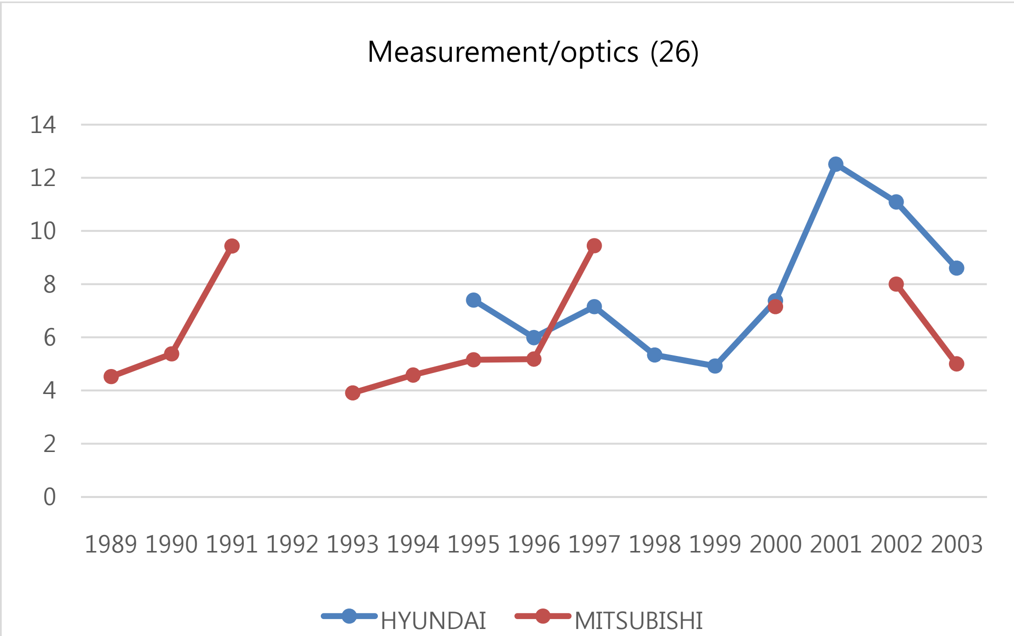

Figure 4.19 The backward citation lag of Hyundai Motor and Mitsubishi's patents in measurement/optics(26)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI			13.1667			8.5000	5.6958	6.2847	6.7528	9.1667	6.1611	6.3422	6.5545	10.2133	15.0000
MITSUBISHI	6.4554	2.0000	3.5333		6.5000	5.7723	12.1667	3.1167	6.7143	4.9643	7.0000	3.4000	2.8000	9.2500	

Table 4.16 The backward citation lag of Hyundai Motor and Mitsubishi's patents in computer (27)

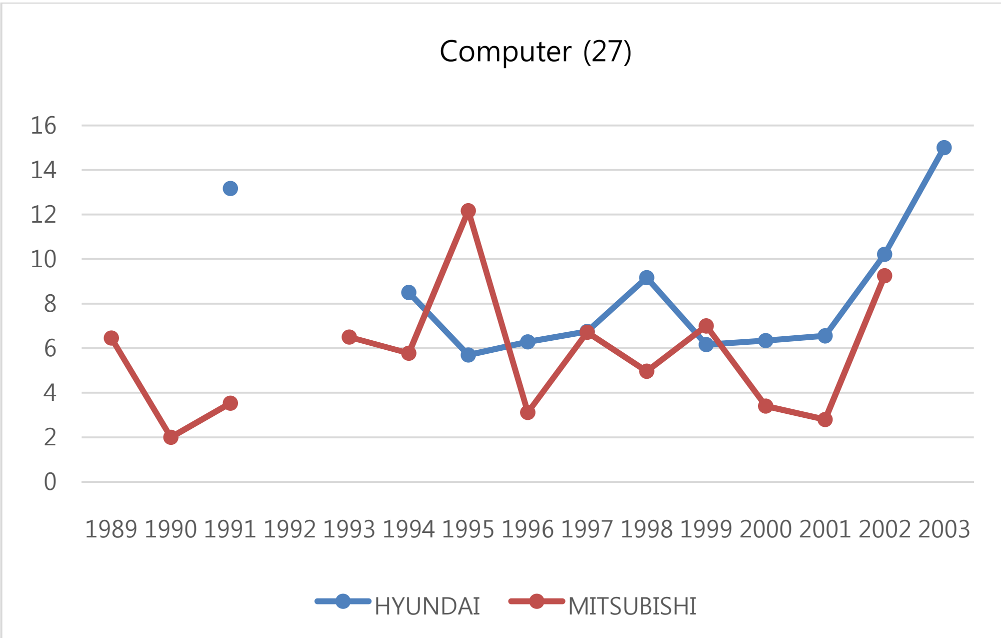

Figure 4.20 The backward citation lag of Hyundai Motor and Mitsubishi's patents in computer (27)

In the engine/pump (22) subsection, Mitsubishi has been developing shorter cycles of technologies. Although Mitsubishi has still led Hyundai in most fields, Hyundai approached their technology level in transport/packaging (10) and computers (27). For mechanical components (23) and measurement /optics (26), we can look only into the analysis of Hyundai since Mitsubishi has not filed many patents since the late 1990s. In conclusion, Mitsubishi has acquired more up-to-date technologies overall, but Hyundai has acquired cutting-edge technologies in the subsections of transport/packaging (10) and computers (27).

3.4 Level of technological dependence

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Hyundai	7.50%	0.00%	2.45%	4.39%	2.65%	2.78%	3.31%	1.34%	1.39%	1.24%	0.75%	1.56%
Mitsubishi	0.00%	0.00%	0.51%	0.00%	0.00%	0.00%	0.00%	2.33%	0.43%	0.00%	0.24%	0.00%

Table 4.17 Percentage of the citations directed to the counterpart firm's patents among total citations

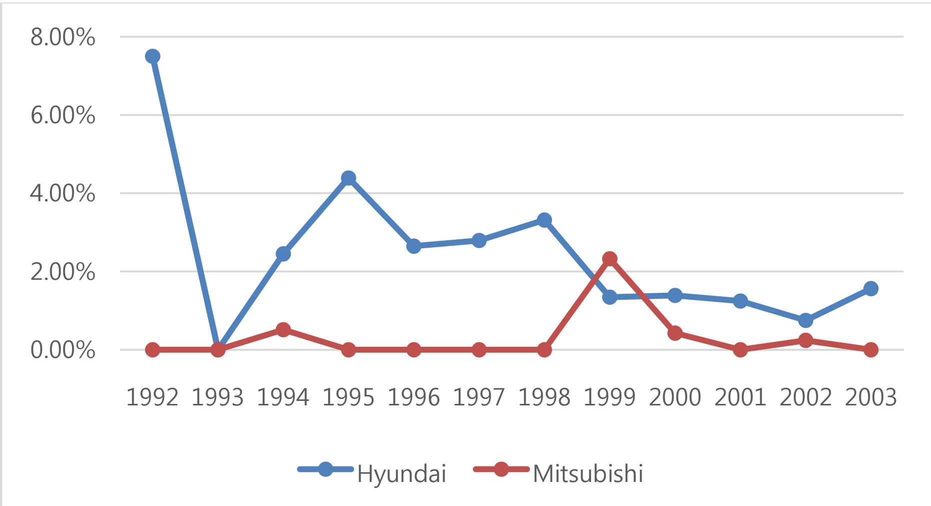

Figure 4.21 The share of citations directed to the counterpart firm's patents

Since 1995, the trends show that Hyundai has gained more independence from Mitsubishi.

3.5 Self-citation ratio

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Hyundai	0.50%	0.00%	0.50%	1.86%	0.71%	1.17%	0.77%	0.46%	0.23%	0.22%	4.54%
Mitsubishi	0.74%	0.39%	0.95%	0.58%	1.02%	0.57%	0.40%	0.30%	0.66%	0.16%	0.29%

Table 4.18 percentage of self-citation ratio Hyundai and Mitsubishi

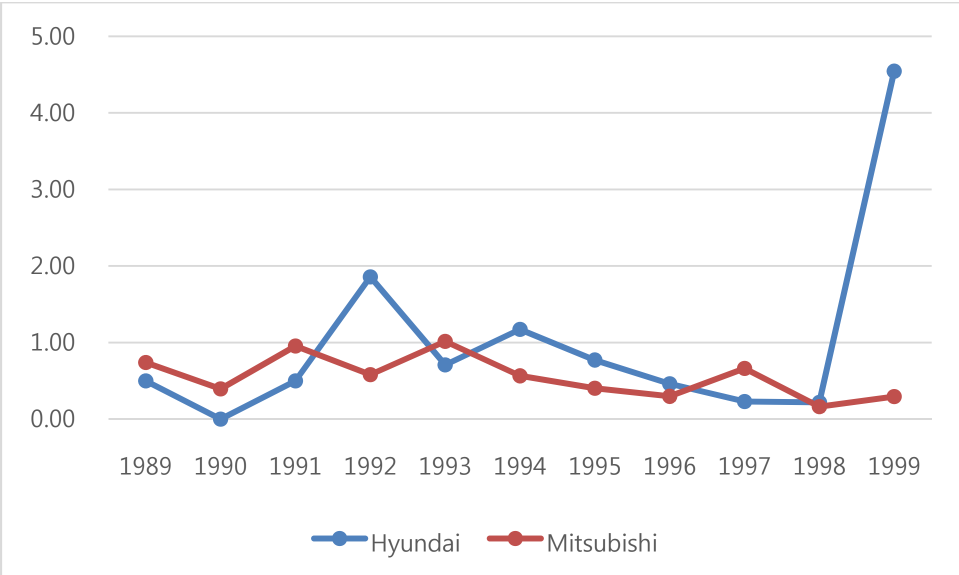

Figure 4.22 Self-citation ratio of Hyundai and Mitsubishi

Since 1990, Hyundai showed an increasing trend in the portion of self-cited patents in general.

3.6 Citations to non-patent literature as science-base

The data files provided by NBER do not provide information related to non-patent literature (NPL). Therefore, we drew a conclusion from an analysis of the PATSTAT database. NPL is divided into two types. The first type provides detailed information such as the title of the paper, author, sources, and the volume number. The second type indicates only the fact that the NPL is cited.

We designate the first type as NPL_CNT and the second type as NPL_MAX. There are minimal differences in patterns between the two types. The results for the average number of citations to NPL by Hyundai and Mitsubishi are as follows.

APPYEAR	1989	1990	1991	1992	1993	1994	1995	1996
HYUNDAI	0	0	0	0	0.0417	0.0345	0.1111	0.0192
MITSUBISHI	0.0263	0	0.5952	0.2927	0.4918	0.4545	0.2045	0.1707

APPYEAR	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	0.0721	0	0.0606	0.0347	0.0612	0.066	0
MITSUBISHI	0.0779	0.1591	0.2667	0	0.0417	0.1034	0.0526

Table 4.19 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi

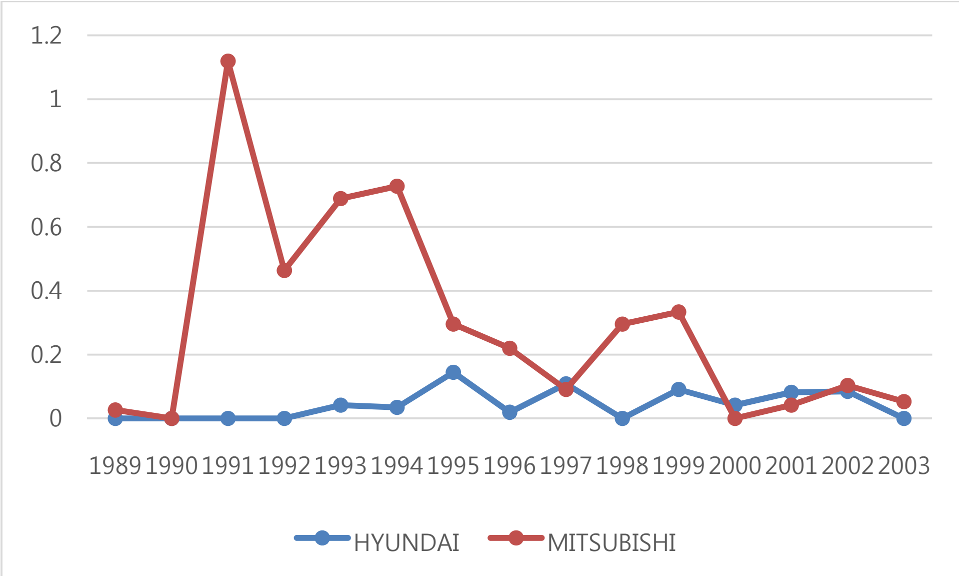

Figure 4.23 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi

The analysis for the average number of NPL citations at the firm level shows that the overall citation level of Hyundai does not reach the citation level of Mitsubishi. However, the recent levels are approaching closer.

An analysis in the technological sections shows that Hyundai had not cited as many NPL as Mitsubishi in the core subsections of transport/packaging (10), engine/pump (22), and mechanical components (23). However, in the subsections of measurement/optics (26) and computers (27), Hyundai has had as many NPL citations as Mitsubishi since the late 1990s. The results are shown in Table _.

	1989	1990	1991	1992	1993	1994	1995	1996
HYUNDAI	0	0	0	0	0.0667	0	0	0.029
MITSUBISHI	0	0	1.667	0.333	0.348	0.167	0.167	0.071

	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	0	0	0	0	0.033	0.036	0
MITSUBISHI	0.143	0	0	0	0.111	0	0

Table 4.20 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in transport/packaging (10)

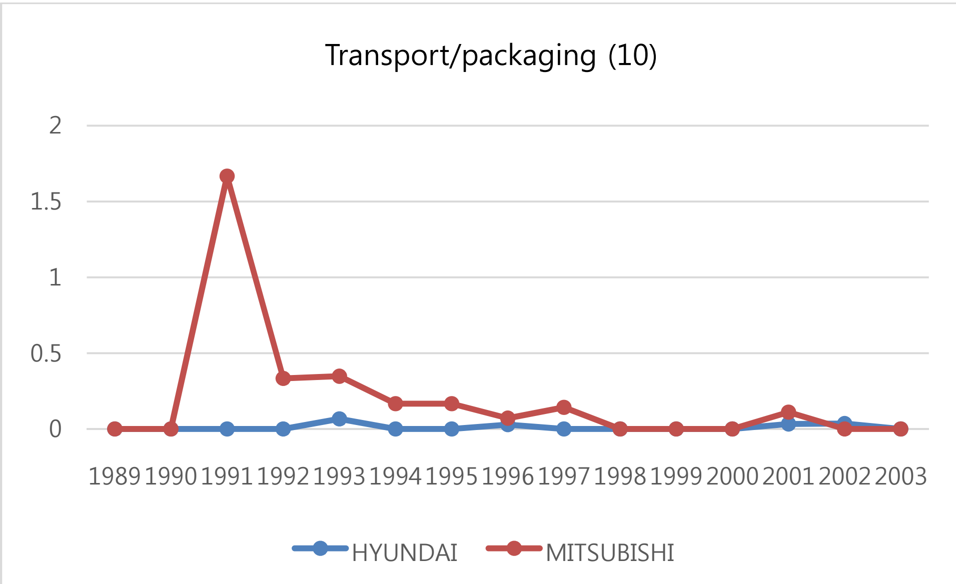

Figure 4.24 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in transport/packaging (10)

	1989	1990	1991	1992	1993	1994	1995	1996
HYUNDAI			0	0	0	0	0	0
MITSUBISHI	0	0	0	0.286	0.810	0.714	0.091	0.071

	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	0	0	0.077	0	0.091	0.138	0
MITSUBISHI	0.075	0	0.25	0	0	0.182	0

Table 4.21 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in engine/pump(22)

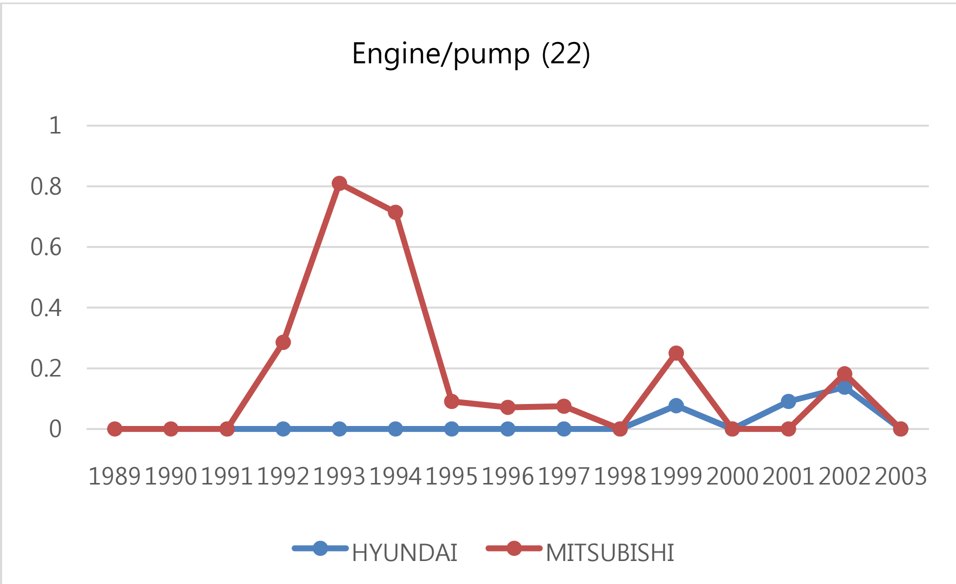

Figure 4.25 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in engine/pump (22)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	0			0	0	0	0.2	0.028	0	0	0	0	0	0	0
MITSUBISHI	0		0	0	0.167	0	0.571	0.25	0	0		0		0	1

Table 4.22 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in mechanical components (23)

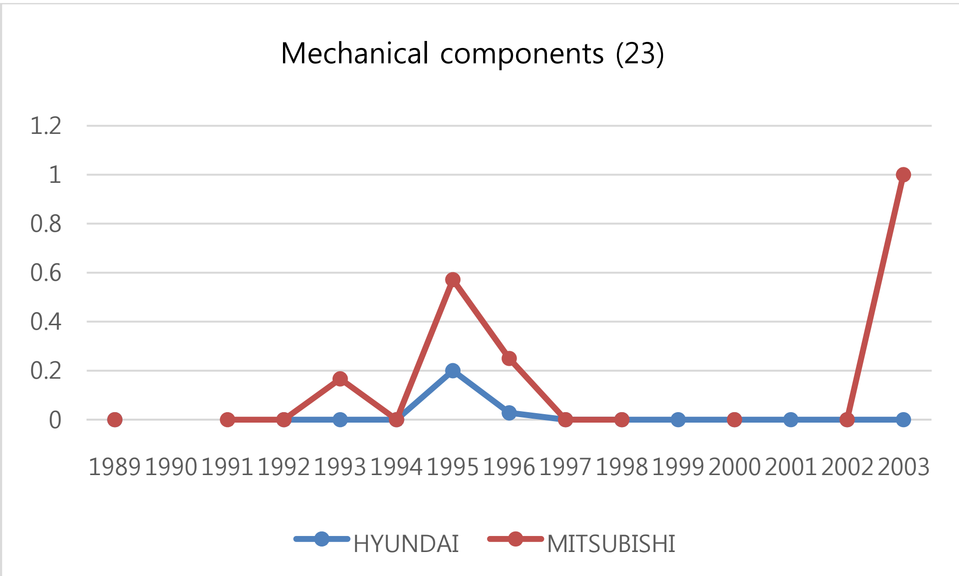

Figure 4.26 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in mechanical components (23)

	1989	1990	1991	1992	1993	1994	1995	1996
HYUNDAI							0	0
MITSUBISHI	0	0	0		1	0.2	1	0

	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	0.25	0	0.5	0.333	0	0.125	0
MITSUBISHI	0			0		0	0

Table 4.23 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in Measurement/optics (26)

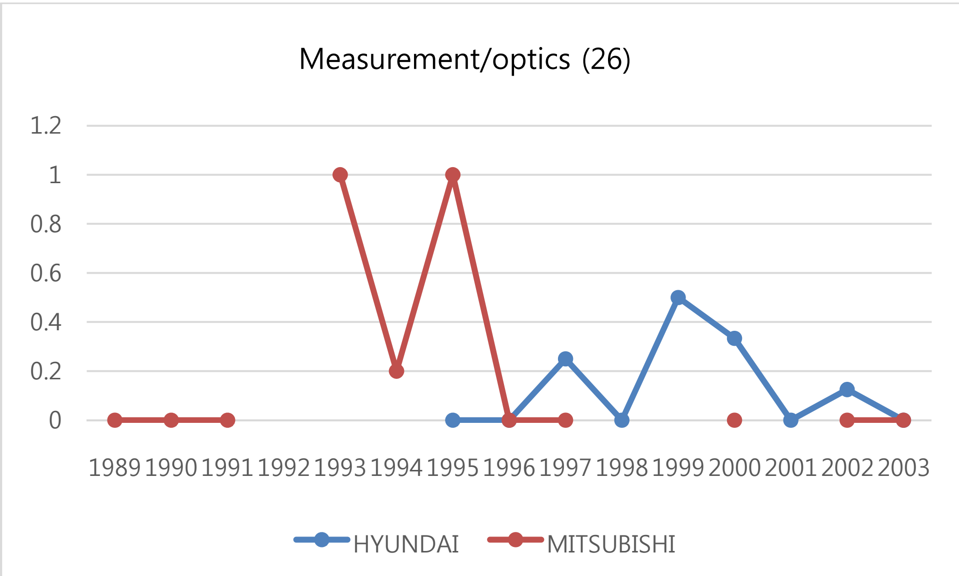

Figure 4.27 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in Measurement/optics (26)

	1989	1990	1991	1992	1993	1994	1995	1996
HYUNDAI			0			0	0	0
MITSUBISHI	0	0	0		0	1.4	0	0

	1997	1998	1999	2000	2001	2002	2003
HYUNDAI	0.714	0	0.111	0.063	0.083	0	0
MITSUBISHI	0	0	0	0	0	0.5	

Table 4.24 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in computer (27)

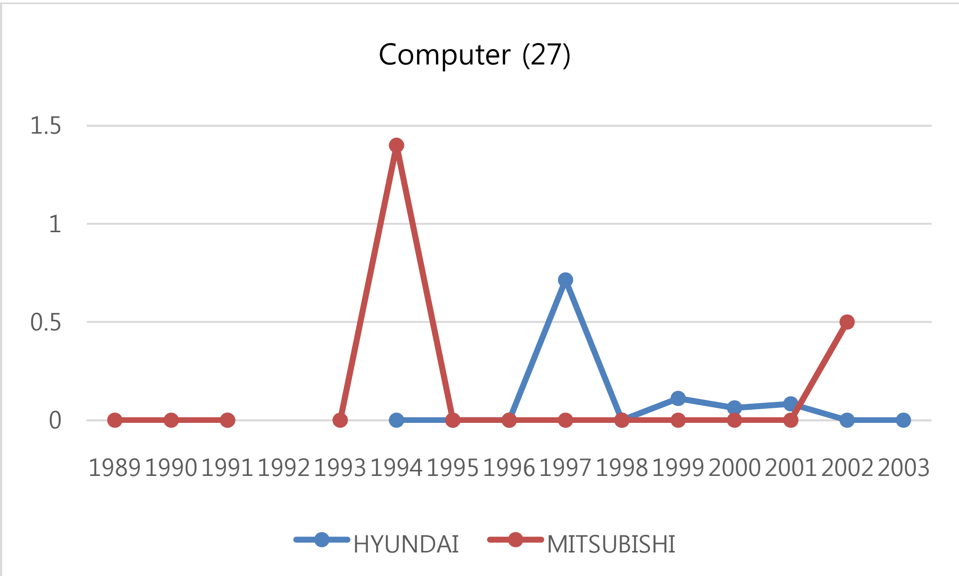

Figure 4.28 Average number of citations to non-patent literature by Hyundai Motor and Mitsubishi in computer(27)

3. Samsung Electronics' Catch-up with Sony

1) Introduction

The case in which Samsung Electronics (hereafter, Samsung) had caught up with Sony Corporation (hereafter, Sony) is one of the more dramatic stories in the electronics industry. In the mid-1990s, Samsung was a very small company and it was unreasonable to compare Samsung to Sony. The brand image of Samsung was so low in the mid-1990s. Samsung's products were displayed only in the low-price electronics sector, which made it impossible to compare Samsung to Sony. In 1996, the gap between Sony and Samsung was more than ten times in market capitalization. The market did not consider Samsung as a competitor to Sony. Samsung was in a developing country South Korea (hereafter, Korea) and handicapped in every aspect. Presently, Samsung has caught up with Sony. Sony is in one of the more developed countries (Japan). The Samsung and Sony case is exceptional and surprising. When comparing Samsung with Sony, it is necessary to review whether the case meets the definition of catch-up discussed in the introduction of this paper..

Many indicators show that Samsung has caught up with Sony in sales revenue and other various areas including high-end products. Business Week rates the brand values of multinational companies in US dollars. The brand value of Samsung in 2000 did not reach a third of Sony's brand value. However, Samsung approached twelve billion dollars in 2004 and widened the gap with Sony by more than five billion dollars in

2005.[32] Also, Samsung began to outpace Sony in market capitalization in 2002. Samsung attained more than one hundred billion dollars in 2006, which was almost twice that of Sony. Samsung dominated Sony in a variety of aspects such as sales revenue, brand value, and market capitalization. It is reasonable to compare Samsung and Sony because they compete in similar technological fields. The five main (the highest proportion to the total patents) technological areas (subsections) are electronics/telecommunication, electricity/semiconductors, information mediums, computers, and measurement/optics. Therefore, it is difficult to compare companies whose technological fields are different, but belong to the same industry sector.

Joo & Lee (2010) conducted an in-depth analysis on the Samsung catch-up with Sony in technological terms. They used the registered patent information and their citations.

In addition, this paper provides more precise indicators to investigate the research questions. We analyze the patents in detail according to their "technological fields" categorized by the IPC sub-section.

Based on the sub-sections for the technology classification of IPC, namely in the five fields – measurement/optics (26), computers (27), information mediums (28), electricity/semiconductors (30), and electronics/telecommunication (31), we conducted a qualitative analysis on the catch-up of the patents in chapter 3.1, the technology cycle (backward citation lag) in chapter 3.2, and citations to NPL as science-

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[32] Business Week from 2000~2005: Joo & Lee, 2010

base in chapter 3.3. The in-depth analysis in each field shows the detailed change of the technologies.

2) Previous literature

We analyze the success story of Samsung with a variety of viewpoints. We will begin with the previous studies that analyzed Samsung's success in terms of technological catch-up. As I mentioned, the catch-up theory in economics has three levels of approach: country level, sectoral level, and firm level. At the country level, Lee and Kim (2009) proved the importance of technological capabilities as one of the most important determinants of long-run economic growth, and more important than openness or integration. At the sectoral level, studies that use the neo-Schumpeterian concept of the sectoral systems of innovations have identified the sectoral differences in the catch-up. Both Lee and Lim (2001) and Mu and Lee (2005) explained the technological catch-up of latecomer firms in developing countries in relation with the technological regime. Especially, Lee and Lim (2001) conducted a detailed analysis about the innovation process of Samsung in chapter 4.2 (D-RAM industry) and in chapter 4.3 (Telecommunication industry: Code Division Multiple Access (CDMA) cellular phone). This paper classifies the case of Samsung's catch-up in D-RAM as a stage-skipping catch-up and the case in CDMA as a path-creating catch-up. Although they do not make an analysis of Samsung in detail, Park and Lee (2006) also revealed by using the U.S .patent data that the economies with a high level of technological capability, such as Korea and Taiwan, produced good achievements in sectors with short cycles of technological change in which technologies quickly replace the previous technologies. The results of this study are in accord with the concept of "window of opportunity" opened by a rapid technological change mentioned in Perez and Soete (1988) and the argument in Amsden and Chu (2003) that the competitiveness of the catch-up firm depends on its capability to enter new market segments quickly, to manufacture with high levels of engineering excellence, and to be the first to market through the best integrative designs. Finally, Joo & Lee (2010) conducted a technological analysis that compares Samsung and Sony at the firm level. The study especially deals with the catch-up of Samsung with Sony in technological terms using the information on patents registered in the US by Samsung and Sony and their citations received.

Sony vs. Samsung (Chang, 2008) made an in-depth analysis on the factors leading to the success of Samsung in terms of strategy, but not in terms of technological catch-up. This book made a detailed comparison of the differences between the two companies' strategies about the new trend in the digitalization of the electronics industry. The book points out that Sony strived to elicit the synergic effect between hardware and contents by utilizing the network, while Samsung's strategy was to secure the competitive superiority by focusing on the core parts. The book also argues that the different strategies are not the only factor of the catch-up. The internal organizational process and the leadership of corporate executive officers (CEOs) played an important role in determining the fate of Samsung and Sony.

The business strategy of a company, organizational process, designs, brands, and marketing are important in the success of a business. However, there is no denying that technological innovation is an essential component in the success of a business considering the sectoral characteristics of the electronics industry. In this regard, Joo & Lee (2010) conducted an in-depth analysis on the catch-up of Samsung with Sony in technological terms, and provided a deep insight to the case.

3) Samsung's catch-up with Sony in the electronics industry.

3)-1 A brief introduction of Samsung and Sony.

Samsung has a huge electronic display at Times Square in Midtown Manhattan, New York. Samsung also ranks third in market capitalization and follows Apple and Google among the world information technology (IT) companies in 2013. Surprisingly, Samsung ranks ahead of Microsoft and International Business Machines (IBM), each of which ranks fourth and fifth.

Samsung had a starting capital of 330 million Korean Wons in January 1969. After establishing a secured hold in the domestic market for a certain period of time, Samsung advanced into the US Market by setting up Samsung Electronics America (SEA) in 1978. SEA is Samsung's local U.S sales corporation.[33] When Samsung imported essential parts from Japan, they buckled down with the development of semiconductors and established an R&D center to develop a technology that produces very large scale integrated (VLSI) semiconductors in 1981. Samsung's strategy focused on the production of d*ynamic random-access memory* (DRAM). Samsung declared the advanced technology into the semiconductor business in March 1983.[34]

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[33] Euibum Park, Global Management: Case 100, 2009

[34] Chang, 2008

Timely decisions are very important in the semiconductor industry. Especially, memory semiconductors go through fluctuating price changes according to supply and demand. Semiconductors have a short life cycle between generations. In the case of DRAM, the price usually plunged to less than one fifth of the original price within a year or two after the initial production, which makes it more important to execute a timely investment and secure a leading position through advanced development.

Samsung was the first developer of 64K DRAM in Korea in less than six months after the declaration of their advanced technology into the semiconductor business. In the first half of 1984 (one year later), the price of 64K DRAM plunged from four dollars to seventy cents. Samsung narrowed the gap with the leading companies in developed countries within one year.
[35]

Later, Samsung realized the trend of IT from analog to digital technology ahead of Sony. Samsung increased the weight of the newly emerging Flash Memory and decreased the weight of traditional DRAM in the semiconductor sector. As Samsung expected, the demand for Flash memory increased significantly due to the explosive growth of MP3 players, digital cameras, and other portable electronic devices in the 2000s. Samsung became the world's third biggest IT company in 2013 and followed Apple and Google in market capitalization. The digital age began through the striking success in the market of smart phones.

[35] Sejin Chang, Strategic management in the age of global competition, 2007

Sony was initially named Tokyo Tsushin Kogyo. The name changed to Sony in 1958. Sony advanced into the US market by establishing a local corporation (Sony USA) in 1960. Sony's advancement into the US market was twenty years earlier than that of Samsung. Sony experienced some hardships before becoming a global leader. They developed the world-hit product Walkman in 1979. Sony advanced into Ireland's market by building local factories through direct investment as its globalization strategy.

Sony aimed to gain a foothold in the European markets, but the results were unsatisfactory. Sony ended up paying a large amount of tuition fee in the global management of factories by closing the local factories due to the lack of the workers' experience and the low quality of locally procured parts. In 1960, which was 12 years after the establishment of the local corporation, Sony began to produce television (TV) products with an assembly line. Later, the Sony Walkman was introduced to the market on July 1, 1979. The Sony Walkman was the outcome of its long development and efforts. In 1978, Sony's radio and recorder producing team experienced a liquidation crisis due to slack sales. The founder of Sony, Akio Morita and Masaru Ibuka, took great pains to name the product Walkman. The Sony Walkman was micro-player size, 8.8 centimeter width and 13 centimeter length, with no recording function.

At that time, hi-fi stereos were popular with North Americans. No one wanted to buy the compact cassette player at the price of $200. However, youngsters striving for new culture earnestly welcomed the Walkman, which eliminated the stereotype that music can only be appreciated indoors. Now, individuals can listen to music anywhere and anytime without the concern of disturbing others. Sony's sales volume went beyond 100 million units in 1993 and reached 350 million units later. Sony led the revolutionary change in music appreciation and continued to evolve in the market environment. Sony was the last hero of the analog generation.

The big hit of Walkman set Sony on a fast track. Sony advanced into the market of computer monitors and took over a semiconductor factory from Advanced Micro Devices (AMD).[36] Since 1995, Sony has advanced into the business of software and multimedia. However, the advent of the digital age forced Sony to confront tough challenges. Sony has recently entered the entertainment industry with huge investments in movies, games, and music, which are not Sony's main areas of business.

Sony intended to make up the competitive edge of hardware products with software. However, during the process, Sony ignored an essential component of a company- the technology. As a result, Sony greatly lagged behind Apple's iPod in the music industry. In the case of TV, Sony missed the investment time in *liquid-crystal display* (LCD) panels and lost the competitive edge. Presently, Sony is provided with LCD panels that are manufactured by Samsung. Sony focused on the entertainment industry, which has not shown any meaningful outcome. The electronics industry was a cash cow for Sony. However, Sony is now confronting a crisis in the digital age. Sony ran a deficit in four consecutive years (2008 to 2011). The scale of deficit in 2011 was more than 5,200 yens,[37] which led to the massive lay-off of more than ten thousand workers.[38] Without

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[36] Euibum Park, Global Management: Case 100, 2009

[37] 7 trillion 300 billion Korean Wons

[38] JP News

the kind of revolution Sony experienced in the past such as the development of the Walkman during analog times, Sony could have difficulties regaining their previous position as a global leader.

Sony and Samsung have been compared to each other. Sony represents Japan's IT business and their sales revenue and brand value, while Samsung is the number one company in Korea with the same environment. Samsung and Sony's business areas and technological fields overlap, which makes it inevitable to compare the two companies.

3)-2 Samsung's catch-up in the market.

Figure 4.29 compares the sales revenue of Samsung and Sony from 2000 to 2006.

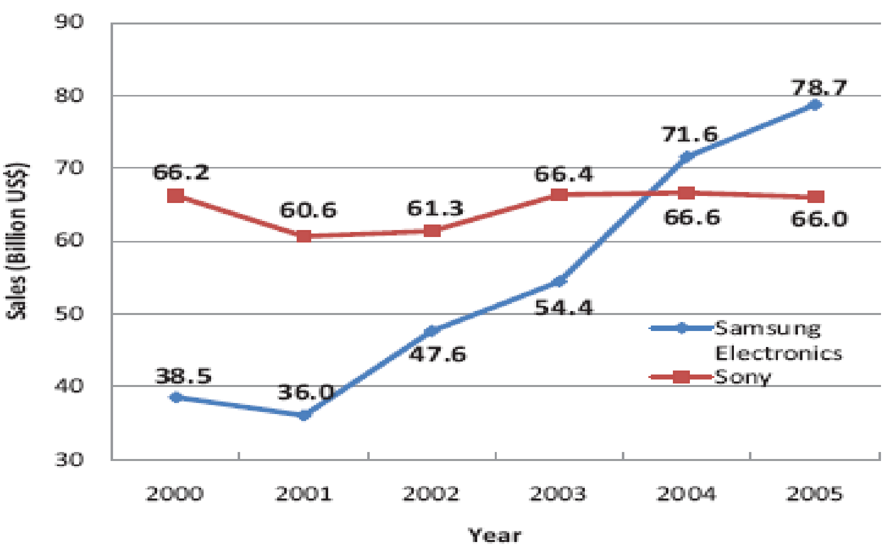

Figure 4.29 Sales of Samsung and Sony. Source: Fortune (2001, 2002, 2003, 2004, 2005, 2006)

As shown in Figure the sales revenue of Sony had been stagnant from 2000 to 2006. Samsung began to lead Sony in 2004 and continued to increase sales revenue, which more than doubled. In addition, Samsung led Sony in every aspect including the brand value and market capitalization in the stock market, which is explained in depth in chapter (Joo&Lee, 2010).

3)-3 Patent data analysis of Samsung and Sony (by sub-section of IPC analysis)

Based on the patents registered at the USPTO, we conducted an analysis of the Samsung and Sony patents in terms of quality, technology cycle, and citations of NPL. For the analysis, we used information about the invention patents of Samsung and Sony registered from 1984 to 2008 at the USPTO. For the analysis of the citations, we used the database of the US patent constructed by Hall and that of the NBER. Joo & Lee (2009) already conducted a patent analysis of Samsung and Sony. This study analysis process compared the technological proximity and degree of technological overlap between Samsung and Sony, which proved the validity of the technological comparisons of the two companies. Therefore, we will skip these steps. This paper conducted a more in-depth analysis of the patents according to the categorization of IPC: measurement/optics (26), computers (27), information media (28), electricity/semiconductor (30), and electronics/communication (31).

3.1 Catch-Up in terms of the quality of patents

Table below (Joo & Lee, 2010) shows the analysis of the average number of received citations at the firm level. The analysis reveals that the patents of Samsung have received more citations than the patents of Sony since 1992. A more detailed analysis of the average number of received citations at the firm level according to the technological sectors is as follows.

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Samsung	8.00	8.00	9.29	8.10	8.31	8.50	8.13	9.25	10.07	10.30	9.01
Sony	12.96	12.97	13.12	12.62	13.32	10.99	11.05	10.53	9.49	9.51	7.66

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Samsung	6.84	5.86	5.18	4.14	2.68	1.65	0.77	0.24	0.05	0.00
Sony	7.09	5.67	4.92	3.21	1.94	0.84	0.39	0.16	0.04	0.01

Table 4.25 Average number of citations received by Samsung Electronics and Sony

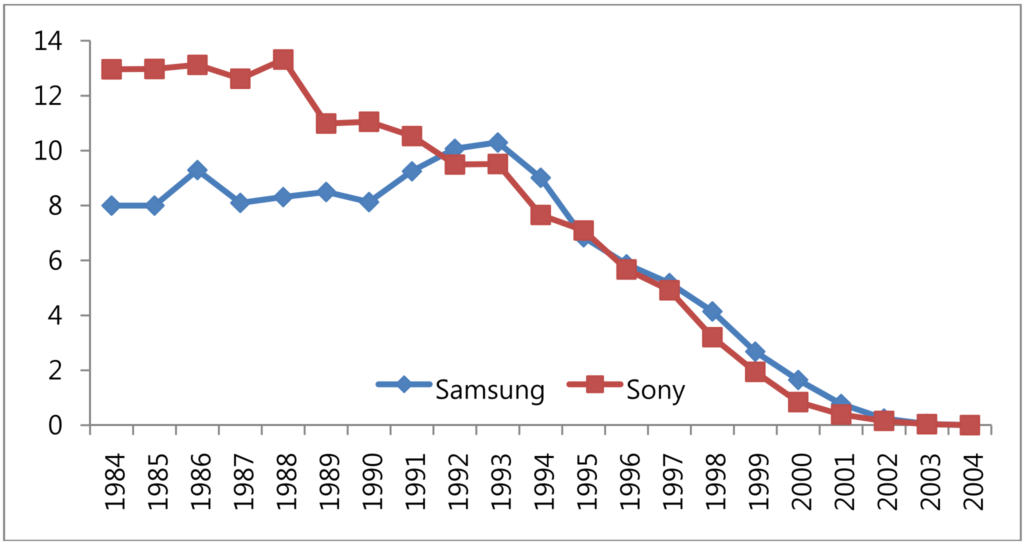

Figure 4.30 Average number of citations received by Samsung Electronics and Sony

	1986	1987	1988	1989	1990	1991	1992	1993
Samsung	14.000	7.500	11.750	1.800	8.700	7.000	5.433	6.480
Sony	7.769	4.667	10.706	6.333	8.382	7.000	7.043	7.525

	1994	1995	1996	1997	1998	1999	2000
Samsung	3.289	3.123	2.212	1.820	0.855	0.438	0.056
Sony	3.247	2.806	2.051	1.100	0.573	0.154	0.000

Table 4.26 Average number of citations received by Samsung Electronics and Sony In Measurement/optics (26)

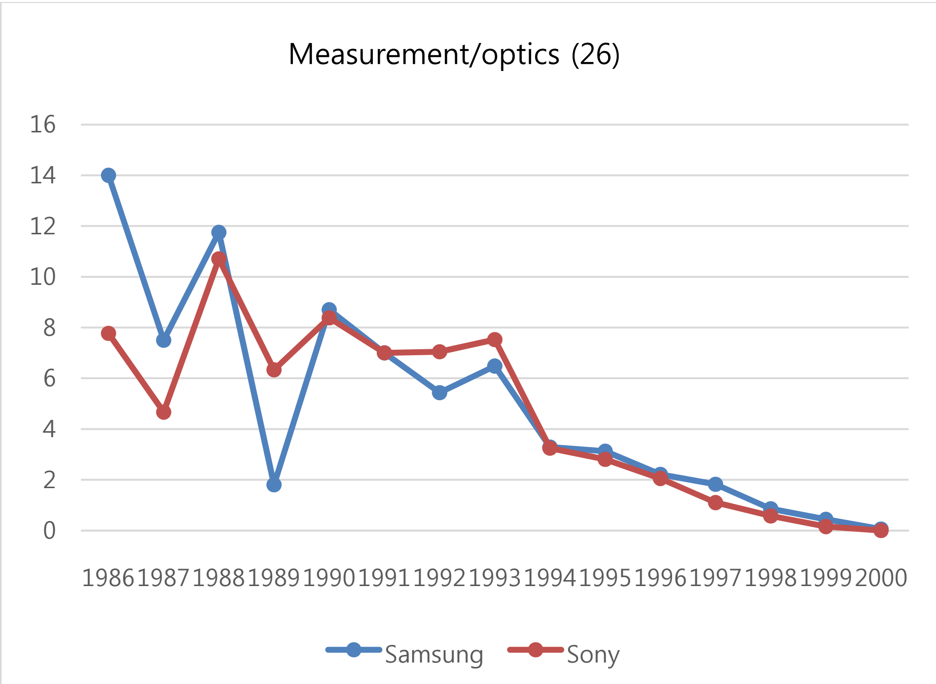

Figure 4.31 Average number of citations received by Samsung Electronics and Sony In Measurement/optics (26)

	1986	1987	1988	1989	1990	1991	1992	1993
Samsung	12.000	2.333	3.444	12.063	6.971	7.189	4.561	8.514
Sony	14.565	16.150	13.550	7.774	10.556	5.867	6.411	5.182

	1994	1995	1996	1997	1998	1999	2000
Samsung	4.764	4.082	2.238	1.009	0.716	0.300	0.000
Sony	3.594	2.727	2.659	1.462	0.921	0.357	0.167

Table 4.27 Average number of citations received by Samsung Electronics and Sony In Computer (27)

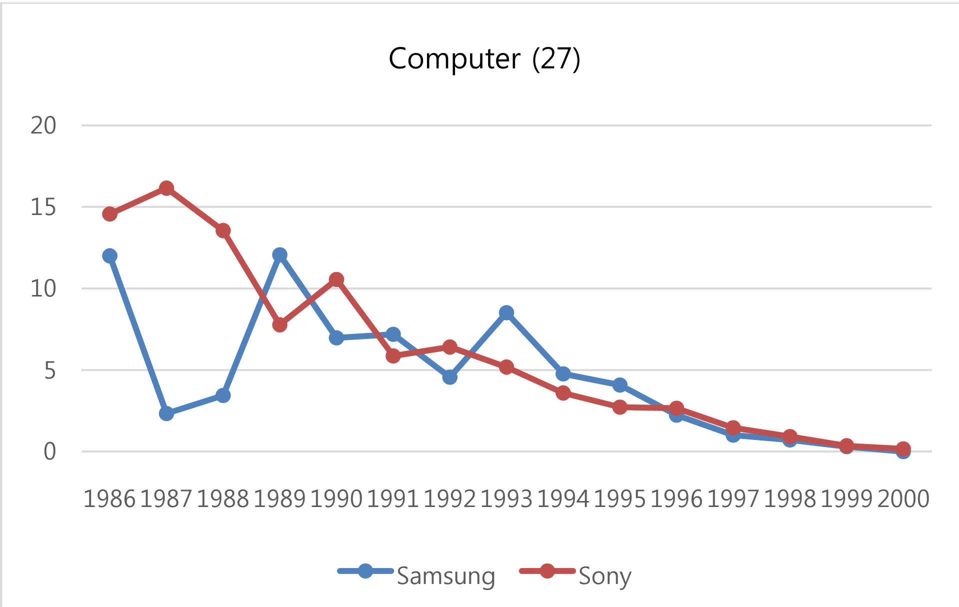

Figure 4.32 Average number of citations received by Samsung Electronics and Sony In Computer (27)

	1986	1987	1988	1989	1990	1991	1992	1993
Samsung	12.200	6.000	6.621	6.941	7.347	5.448	7.978	5.854
Sony	11.691	10.730	10.087	8.198	8.571	7.680	6.163	5.481

	1994	1995	1996	1997	1998	1999	2000
Samsung	5.416	4.234	2.608	1.772	1.020	0.358	0.070
Sony	3.793	3.599	1.813	0.883	0.377	0.292	

Table 4.28 Average number of citations received by Samsung Electronics and Sony In Information media (28)

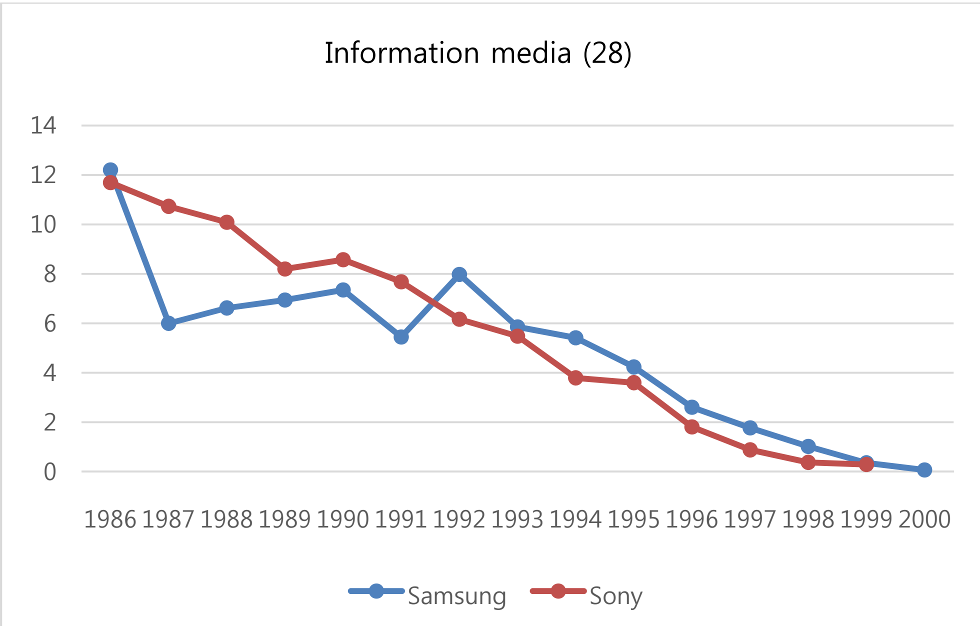

Figure 4.33 Average number of citations received by Samsung Electronics and Sony In Information media (28)

	1986	1987	1988	1989	1990	1991	1992	1993
Samsung		6.800	5.613	9.433	9.475	13.485	11.748	9.538
Sony	8.875	7.543	11.500	9.651	8.738	9.500	6.624	5.033

	1994	1995	1996	1997	1998	1999	2000
Samsung	6.553	4.586	3.682	1.935	1.161	0.639	0.180
Sony	4.394	4.194	2.554	1.549	0.642	0.296	0.143

Table 4.29 Average number of citations received by Samsung Electronics and Sony In Electricity/semiconductor (30)

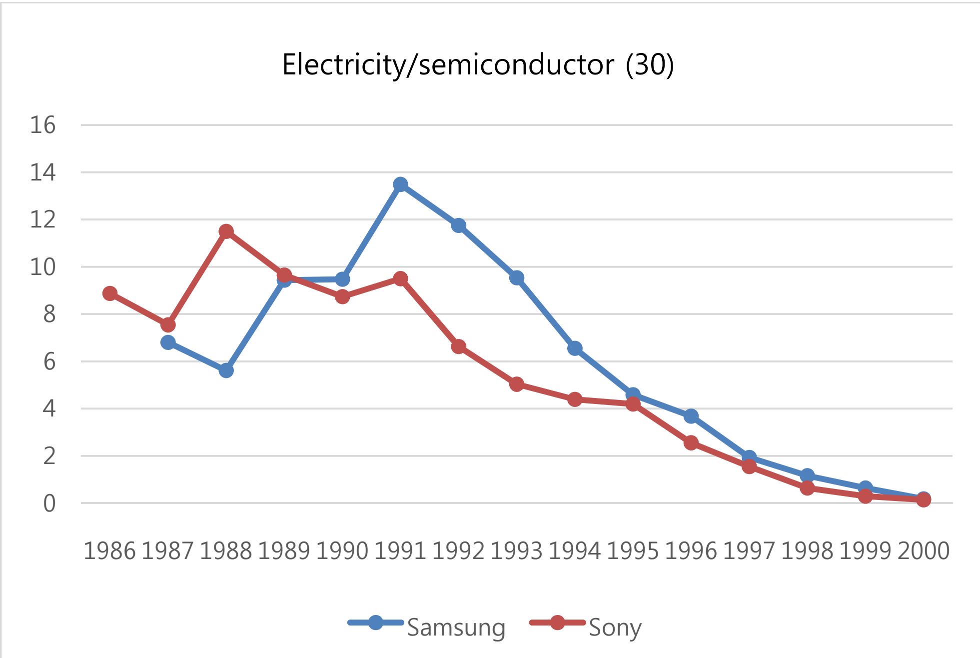

Figure 4.34 Average number of citations received by Samsung Electronics and Sony In Electricity/semiconductor (30)

	1986	1987	1988	1989	1990	1991	1992	1993
Samsung	6.571	8.235	8.171	5.682	4.618	5.595	6.052	5.964
Sony	12.286	11.030	11.716	11.467	8.830	7.602	7.241	6.925

	1994	1995	1996	1997	1998	1999	2000
Samsung	5.026	2.967	1.628	0.974	0.559	0.505	0.061
Sony	4.303	3.095	1.791	1.152	0.318	0.215	0.152

Table 4.30 Average number of citations received by Samsung Electronics and Sony In Electronics/communication (31)

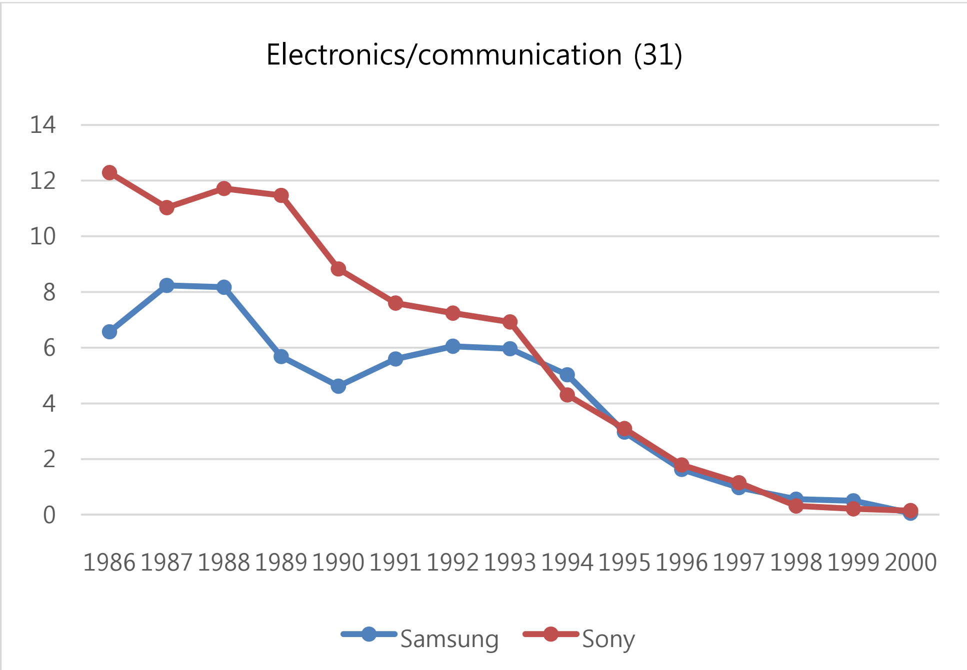

Figure 4.35 Average number of citations received by Samsung Electronics and Sony In Electronics/communication (31)

Figure 4.35 shows that Samsung filed higher quality patents in the field of measurement/optics (26) since 1986. However, Sony led Samsung in 1989, 1992, and 1993. Moreover, Samsung led Sony from 1990 to 2000, but the gap was not large. This leads to the conclusion that Samsung overtook Sony in the quality of the patents during 1996 in the areas of measurement and optics, but the gap was not large.

In the area of computers, Samsung filed higher quality patents than Sony in the early 1990s. However, Sony reversed the trend by filing higher quality patents in the late 1990s. In the area of information media, Samsung began to file higher quality patents since 1992. Samsung's dominance continued until the 2000s.

In the area of electricity/semiconductor (30), Samsung has been filing higher quality patents than Sony since the early 1990s. Sony's dominance had continued until the 2000s. In the field of electronics/communication (31), Samsung overtook Sony in the mid-1900s. However, Samsung and Sony have been competing well into the 2000s.

In conclusion, Samsung's dominance over Sony is obvious in the areas of information media (28) and electricity/semiconductor (30), and slightly in the area of measurement/optics (30) in terms of the patents' quality. The three areas are those in which the technology cycle of Samsung is shorter than that of Sony. This observation is described in the following analysis of backward citation lag.

3.2 Technology cycle (backward citation lag)

The analysis of backward citation lag at the firm level demonstrates in Table 4.31 that Samsung has been developing technologies with a shorter technology cycle than that of Sony (Joo & Lee, 2010). A more detailed analysis of the technology sector requires the correspondence of the technology areas of Samsung and Sony, whose five technology areas are the same: measurement/optics (26), computers (27), information media (28), electricity/semiconductor (30), and electronics/communication (31). Among the five areas, the backward citation lag of Samsung is shorter in the three areas of measurement/optics (26), information media (28), and electronics/communication (31). However, Samsung has been competing with Sony in the areas of computers (27) and electronics/communication (31). The backward citation lag of Samsung is shorter than that of Sony in the three technology fields in which Samsung overtook Sony in terms of quality.

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Samsung	1.978	11.08	4.687	4.426	4.807	4.817	5.174	4.287	4.253	4.409	4.036	4.162	4.292
Sony	4.049	4.25	3.547	3.493	3.847	3.247	3.703	3.414	3.253	3.556	3.222	3.378	3.183

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Samsung	3.788	2.963	2.843	2.862	3.128	3.92	4.003	4.377	4.398	4.514	5.279	6
Sony	2.996	2.94	2.946	2.854	3.363	3.51	4.172	4.593	5.506	6.6	6.941	10.32

Table 4.31 Average Backward Citation Lag

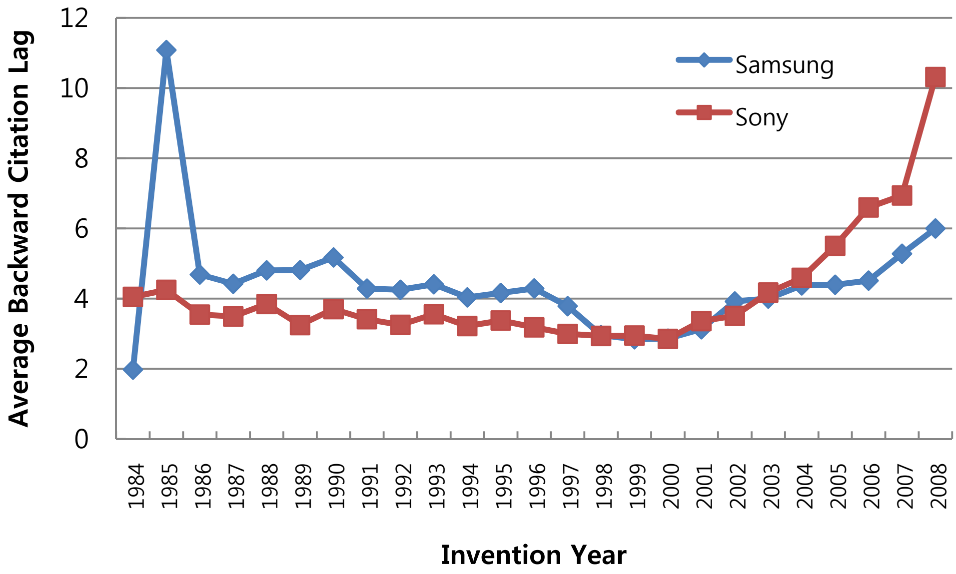

Figure 4.36 Average Backward Citation Lag

	1986	1987	1988	1989	1990	1991	1992
Samsung	4.091	4.250	3.186	8.551	5.060	5.103	5.764
Sony	9.256	10.138	7.638	9.143	8.611	7.688	6.175

	1993	1994	1995	1996	1997	1998
Samsung	6.460	7.156	6.718	6.995	6.387	6.083
Sony	7.464	8.154	8.819	8.523	8.131	14.000

Table 4.32 Average Backward Citation Lag in measurement/optics (26)

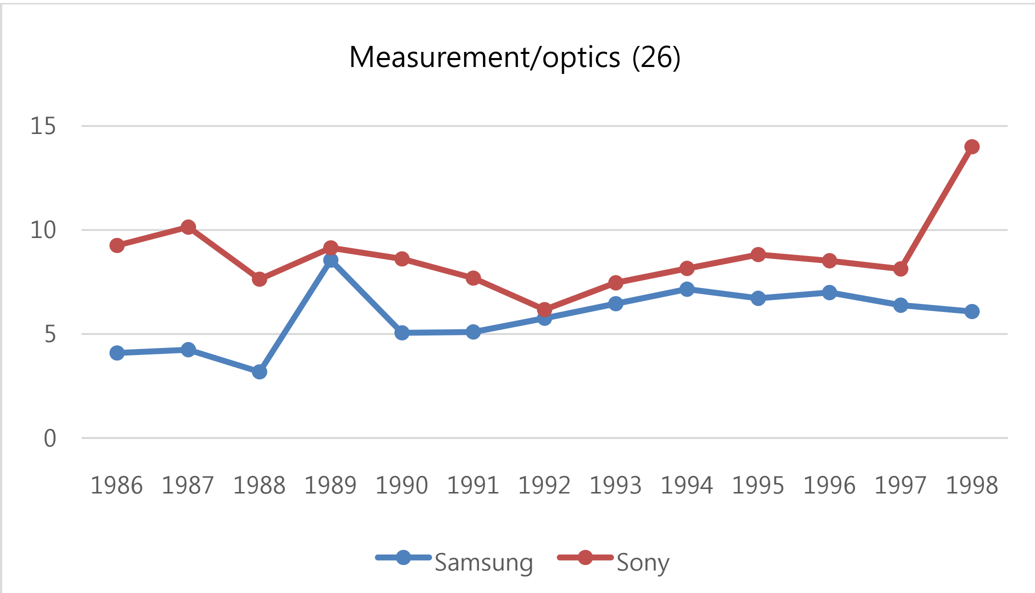

Figure 4.37 Average Backward Citation Lag in measurement/optics (26)

	1986	1987	1988	1989	1990	1991	1992
Samsung	2.667	25.111	8.472	8.903	5.741	6.517	7.365
Sony	4.211	6.465	7.371	6.310	6.543	6.002	6.623

	1993	1994	1995	1996	1997	1998
Samsung	5.921	5.335	5.774	5.319	5.180	3.857
Sony	6.962	5.606	5.476	5.088	4.896	3.806

Table 4.33 Average Backward Citation Lag in computer (27)

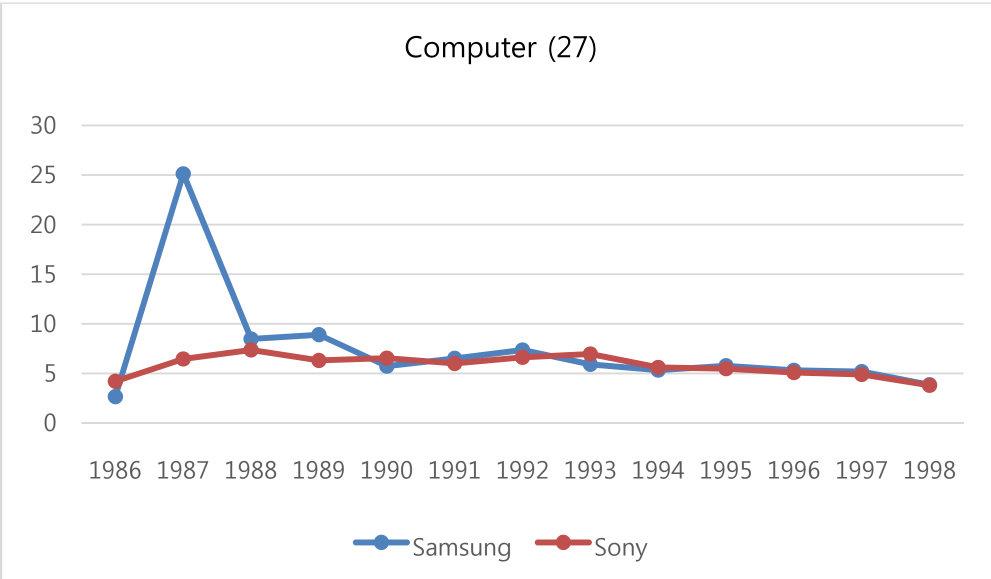

Figure 4.38 Average Backward Citation Lag in computer (27)

	1986	1987	1988	1989	1990	1991	1992
Samsung	3.542	2.250	8.384	5.860	4.858	6.503	5.368
Sony	5.740	5.585	5.771	6.432	6.347	6.233	6.431

	1993	1994	1995	1996	1997	1998
Samsung	5.001	4.886	5.154	5.042	3.625	3.798
Sony	6.060	5.914	5.420	4.901	5.627	4.375

Table 4.34 Average Backward Citation Lag in information media (28)

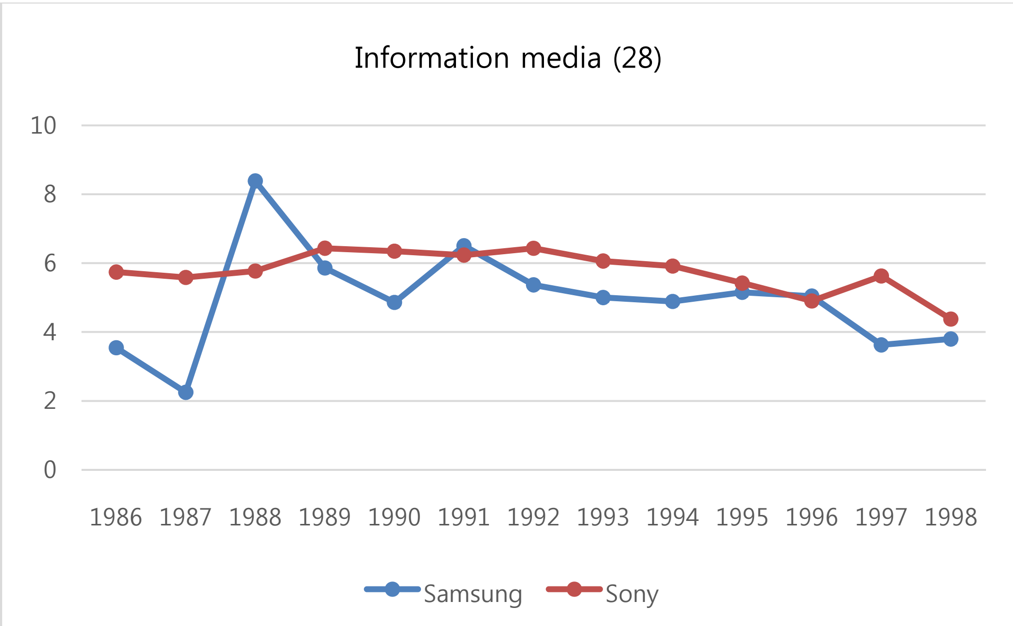

Figure 4.39 Average Backward Citation Lag in information media (28)

	1986	1987	1988	1989	1990	1991	1992
Samsung	0.000	8.078	9.269	6.002	7.653	6.087	6.246
Sony	7.871	9.151	8.593	8.819	8.640	6.760	7.234

	1993	1994	1995	1996	1997	1998
Samsung	6.765	5.917	6.499	6.845	8.781	7.997
Sony	8.274	7.183	7.414	7.294	7.108	6.310

Table 4.35 Average Backward Citation Lag in electricity/semiconductor (30)

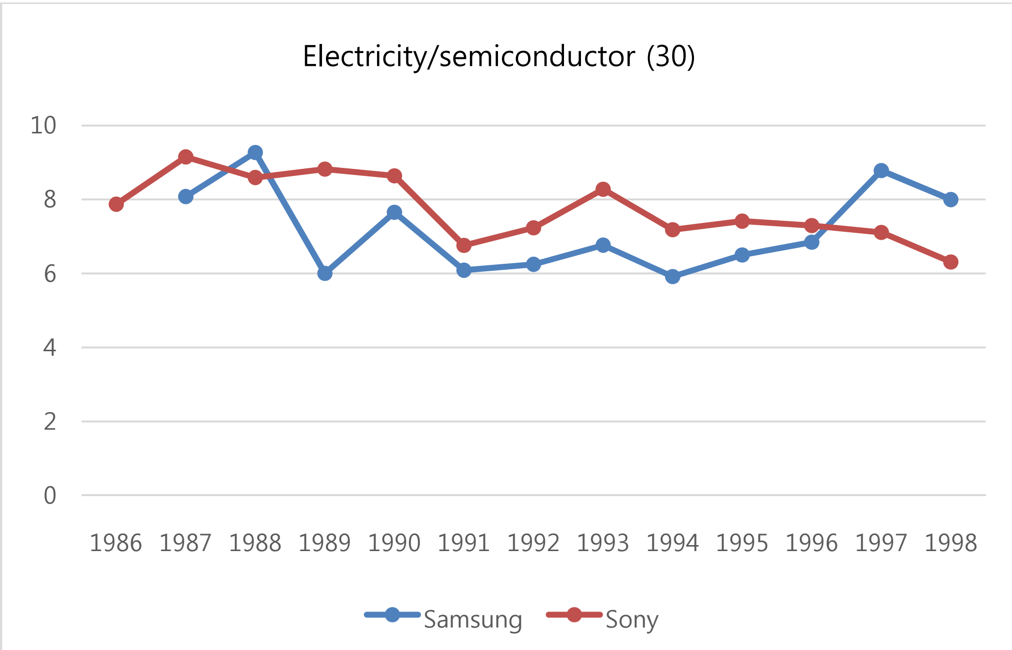

Figure 4.40 Average Backward Citation Lag in electricity/semiconductor (30)

	1986	1987	1988	1989	1990	1991	1992
Samsung	7.181	6.155	6.015	6.645	6.040	5.930	6.342
Sony	5.171	5.531	6.594	5.015	6.430	6.350	5.956

	1993	1994	1995	1996	1997	1998
Samsung	6.383	6.207	6.296	6.204	5.062	4.867
Sony	6.434	5.739	5.850	6.353	6.107	6.415

Table 4.36 Average Backward Citation Lag in electronics/communication (31)

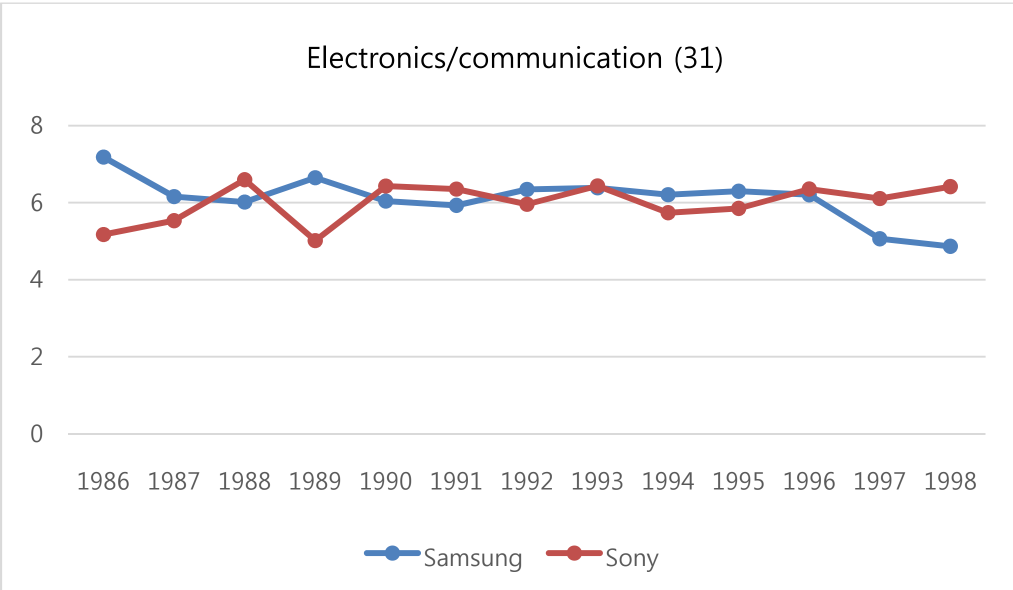

Figure 4.41 Average Backward Citation Lag in electronics/communication (31)

3.3 Citations to non-patent literature as science-base

The analysis of the average number of NPL citations at the firm level shows that the citation degree of NPL of Samsung approached that of Sony in the late 1990s. The following is the results of the analysis for each technology area.

	1986	1987	1988	1989	1990	1991	1992	1993	1994
SAMSUNG	0.529	0.447	0.238	0.288	0.28	0.333	0.465	0.467	0.252
SONY	0.678	0.554	0.799	0.916	0.93	1.304	1.61	1.581	1.296

	1995	1996	1997	1998	1999	2000	2001	2002	2003
SAMSUNG	0.353	0.396	0.68	0.967	0.992	0.976	0.63	0.555	0.838
SONY	1.154	0.939	1.143	0.841	1.012	1.058	0.602	0.413	1.053

Table 4.37 Citation to non-patent literature as science-base

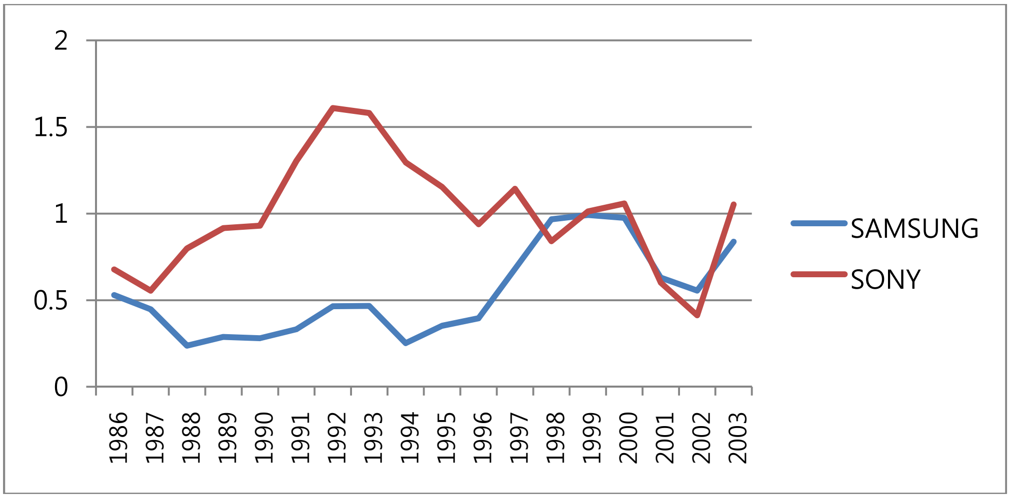

Figure 4.42 Citation to non-patent literature as science-base

	1986	1987	1988	1989	1990	1991	1992	1993	1994
SAMSUNG	0	0	0	0.25	0	0.176	0.222	0.042	0.053
SONY	0.091	0.6	1.471	0.647	1.441	3.302	1.299	0.678	0.8

	1995	1996	1997	1998	1999	2000	2001	2002	2003
SAMSUNG	0.555	0.464	0.428	0.375	0.429	0.9	0.427	0.193	0
SONY	0.5	0.507	0.271	1.034	0.173	0.763	0.466	0.045	1.286

Table 4.38 Citation to non-patent literature as science-base in measurement/optics (26)

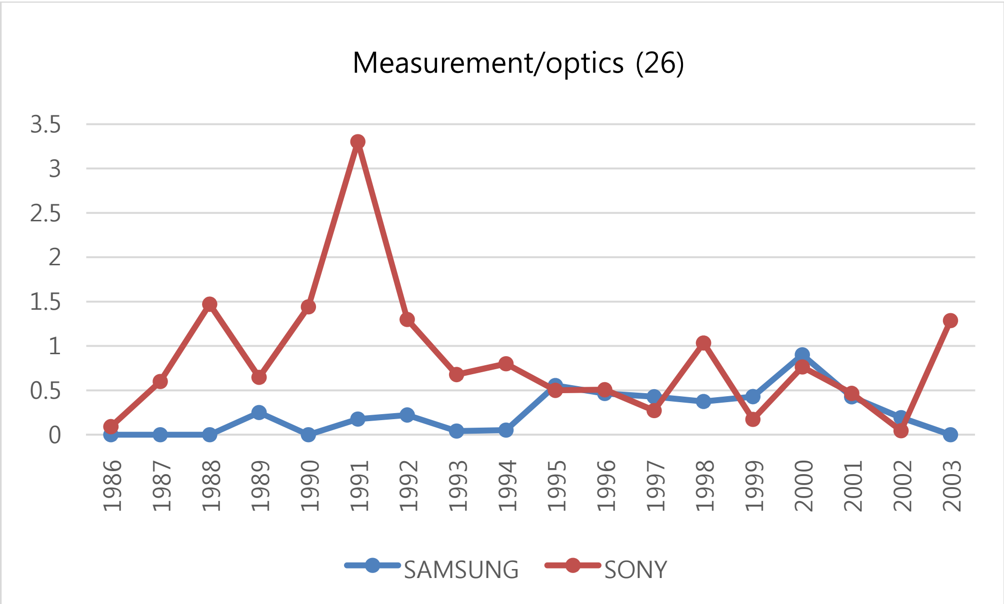

Figure 4.43 Citation to non-patent literature as science-base in measurement/optics (26)

	1986	1987	1988	1989	1990	1991	1992	1993	1994
SAMSUNG	0	0	0.111	0.688	1.382	0.194	0.282	2.129	0.444
SONY	0.364	0.778	1	1.867	0.889	2.033	2.479	1.013	3.391

	1995	1996	1997	1998	1999	2000	2001	2002	2003
SAMSUNG	0.4	0.497	0.805	1.433	0.725	2.73	1.5	0.306	2.5
SONY	5.407	2.216	3.295	2.025	3.395	3.444	0.927	1	

Table 4.39 Citation to non-patent literature as science-base in computer (27)

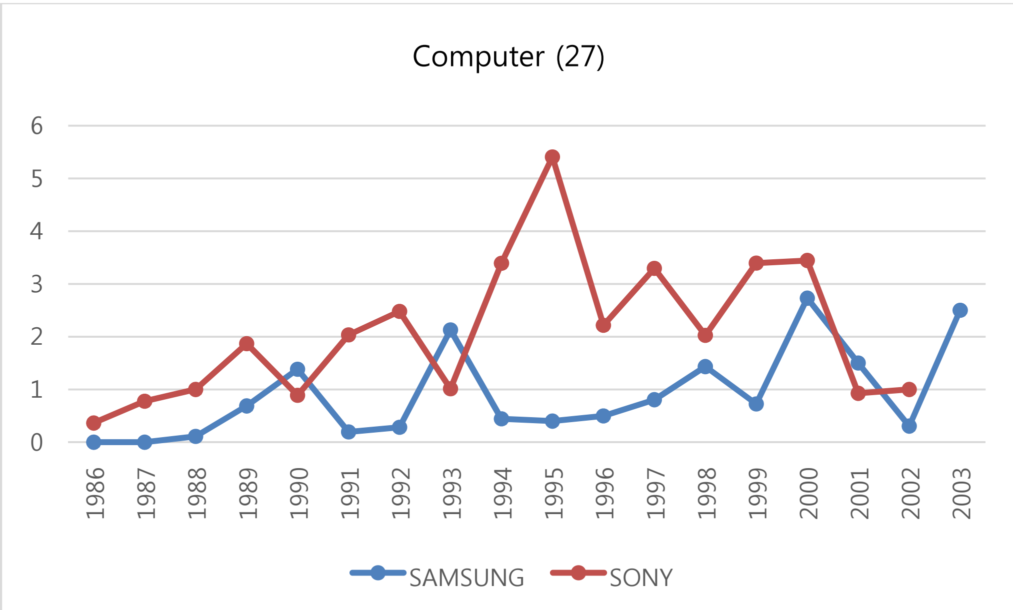

Figure 4.44 Citation to non-patent literature as science-base in computer (27)

	1986	1987	1988	1989	1990	1991	1992	1993	1994
SAMSUNG	0	0	0.222	0.149	0.114	0.337	0.198	0.574	0.145
SONY	0.686	0.358	0.837	0.95	1.122	1.484	1.581	2.355	1.198

	1995	1996	1997	1998	1999	2000	2001	2002	2003
SAMSUNG	0.258	0.316	0.834	1.076	1.527	0.45	0.339	0.301	0.37
SONY	0.82	0.89	1.035	0.722	0.525	0.452	0.329	0.615	0

Table 4.40 Citation to non-patent literature as science-base in information media (28)

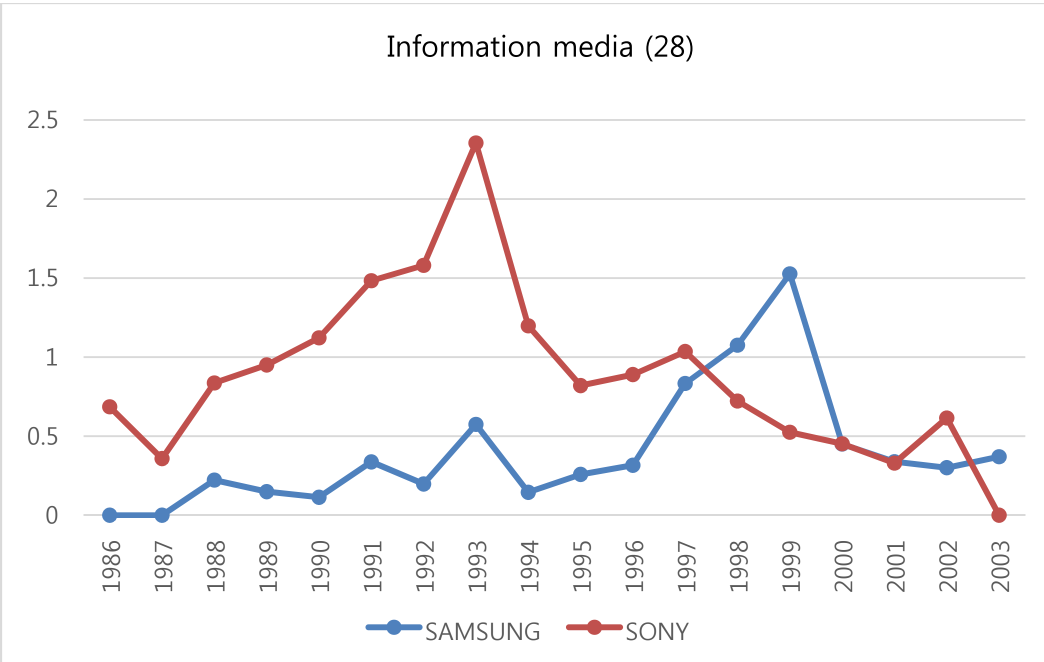

Figure 4.45 Citation to non-patent literature as science-base in information media (28)

	1986	1987	1988	1989	1990	1991	1992	1993	1994
SAMSUNG		0.786	0.194	0.423	0.308	0.737	1.269	0.652	0.222
SONY	1.323	0.697	1.5	1.302	0.628	1.13	1.87	1.444	1.372

	1995	1996	1997	1998	1999	2000	2001	2002	2003
SAMSUNG	0.607	0.637	0.65	0.635	0.531	0.628	0.738	0.889	0.478
SONY	0.399	0.661	0.73	0.778	0.583	0.606	0.913	0.233	2.2

Table 4.41 Citation to non-patent literature as science-base
In electricity/semiconductors (30)

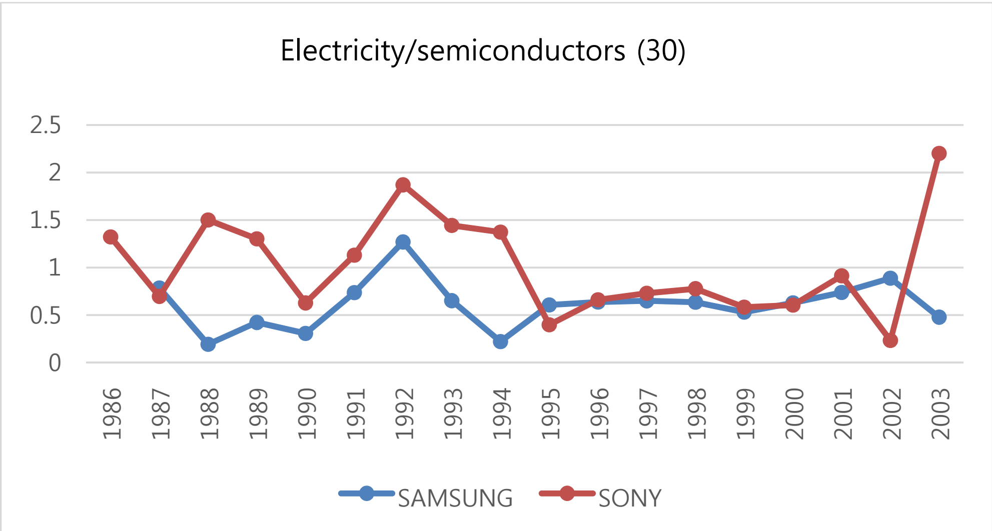

Figure 4.46 Citation to non-patent literature as science-base
in electricity/semiconductors (30)

	1986	1987	1988	1989	1990	1991	1992	1993	1994
SAMSUNG	1.286	0.375	0.348	0.289	0.067	0.193	0.269	0.287	0.298
SONY	0.56	0.737	0.589	0.633	0.897	0.888	1.498	1.455	0.853

	1995	1996	1997	1998	1999	2000	2001	2002	2003
SAMSUNG	0.178	0.251	0.625	1.712	1.144	1.355	0.709	0.275	0.48
SONY	0.595	0.782	0.766	0.32	0.428	0.439	0.34	0.278	0

Table 4.42 Citation to non-patent literature as science-base
In electronics/communication (31)

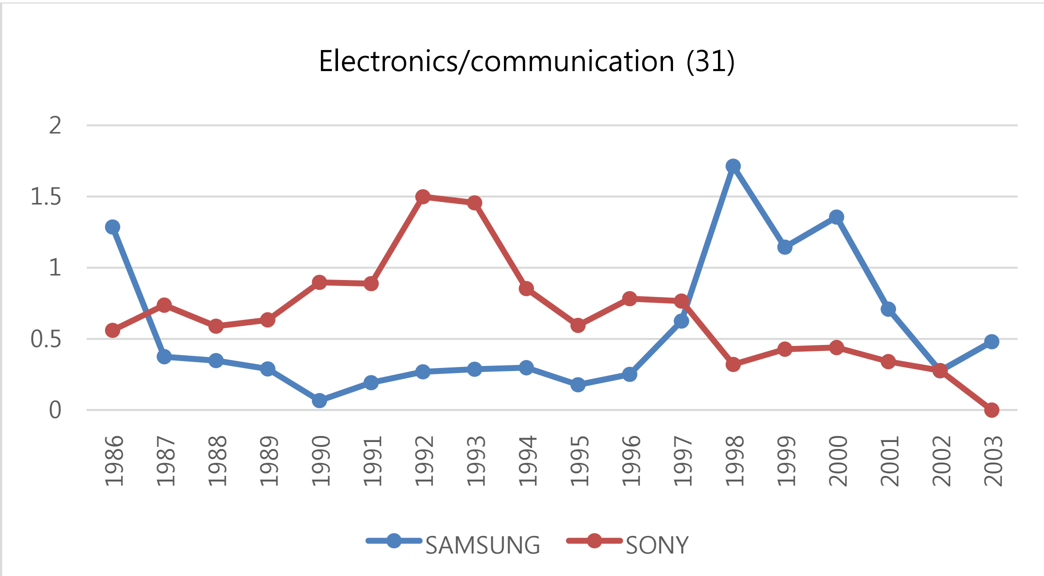

Figure 4.47 Citation to non-patent literature as science-base
In electronics/communication (31)

The citation degree of Samsung's NPL began to be higher or approached that of Sony in the areas of measurement/optics (26) and electricity/semiconductors (30) from 1995 and in the areas of information media (28) and electronics/communication (31) from 1998. We compared the catch-up points of time with the catch-up points of technology in quantitative terms. Measurement/optics (26) in 1995, electricity/semiconductors (30) in 1995, information media (28) in 2001 show the similarities in quantitative terms between the points of time Samsung overtook Sony in technological catch-up. For the points of time, the citation degree of Samsung's NPL began to lead or approach that of Sony. In the area of computers (27), the citation degree of Samsung's NPL was lower than that of Sony.

4. POSCO's catch-up with Nippon Steel Corporation

1) A brief introduction of POSCO and Nippon Steel Corporation

Another case study of a developing company growing steadily based on accumulated technological capabilities is the Pohang Steel Company (hereafter, POSCO). POSCO is a company of Korea with a global standing. POSCO shared its track with the development of Korea in the 1960s and 1970s.

The original name for the Pohang Steel Company was Pohang Iron & Steel Company Limited, which was founded in 1968. President Park, Jeong-heui assigned the task of entering the steel industry market to Tae-joon Park- the CEO of Korea Tungsten Co. Tae-joon Park asked the World Bank and the US steel makers for the technology transfer and capital investment. However, Park was rejected by the request over and over again.[39] As a last resort, Park received the promise of technology transfer from Japan's steel companies through the help of friends from Waseda University Park operated the first blast furnace with a production capacity of one million ton per year in 1973. The second, third and fourth blast furnaces were in 1976, 1978 and 1983, which completed the production facilities with a production capacity of 9.1 million ton.[40]

Later, POSCO began to invest in Gwangyang, Korea in 1985. POSCO completed the Gwangyang Steel Works with an annual production capacity of 1,140 ton. Since then, POSCO has faced several challenges in terms of costs. A low labor wage is the source of POSCO's competitive advantage. Wages have increased with the development of the Korean

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[39] The 25 year history of POSCO, 1989

[40] The 25 year history of POSCO, 1989

economy, and especially, the advancement of steel makers in China and India where the labor costs are low. The wage environment is giving POSCO a serious challenge. In addition, the increase in labor costs in Korea and POSCO's portfolio of low-profit products makes it necessary for POSCO to change and make a long-term management strategy. Steel makers in Brazil, China, and India have been challenging POSCO's dominance with low-cost labor and new facilities. The technological innovation of the steel makers in advanced countries is also a potential threat to POSCO's survival.

Also, the frequent occurrence of recession in the steel industry has been a threat to POSCO. The steel industry cannot downsize production facilities during a recession. The steel mills have to operate continually once the furnaces catch fire. The whole steel industry is in a structural recession with the continuous advances of newcomers due to the oversupply of steel.

In reaction to this situation, POSCO tried to overcome the difficulties by doubting its sustainable dominance in the market. In 2003, POSCO founded a holding company called POSCO China and established eleven affiliated companies including Dalian Pohang Steel Sheet, Jangjiahang Pohang Stainless Steel, and Qingdao Pohang Steel Sheet. In addition, POSCO confirmed a business plan for the construction of an integrated steel mill with an annual production capacity of 12 million ton in the State of Orisa, India in late 2005. By the standards of 2012, POSCO was the second largest steel maker in the world with a high price competitive edge.

Nippon Steel Corporation started its history as a state-owned enterprise in 1901 as Yawata Steel Corporation. A merger with existing medium-sized steel makers in 1934 gave birth to Nippon Steel Corporation (hereafter, Nippon Steel). Nippon Steel was divided into Huji Steel Corporation and Yawata Steel Corporation due to the concentrated regulation of steel companies in 1950. In 1970, the merger of the Huji Steel Corporation and Yawata Steel Corporation created the present-day Nippon Steel Corporation.[41]

Nippon Steel began to emerge as a major global steel maker through the aggressive support of Japan's government and preoccupancy of new technologies in 1970s. Nippon Steel also rationalized facilities and downsized the organization in the 1970s and 1980s.[42] As a result, Japan emerged as the second largest steel maker after the United States. Japan's steel industry has grown rapidly since the 1970s and established its matchless position enough to provide technological support to the US, the traditional steel maker.[43]

In the 2000s, Nippon Steel began to promote hybrid management through advances into related industries.[44] Nippon Steel became the third largest steel maker in the world in terms of sales revenue through the merger with the steel maker *Sumitomo Metal Industries* (SMI) in Japan and the second largest steel maker in terms of crude steel production.[45]

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[41] Nippon Steel Corporation, 2004

[42] POSRI, the survival strategy of steel makers in advanced countries in times of low growth

[43] Economics of catch-up, 2008

[44] POSRI, the survival strategy of steel makers in advanced countries in times of low growth

[45] Woori Investment & Securities Co. Ltd., industry analysis, 2013

2) POSCO's catch-up with Nippon Steel in the market

Figure 4.48 shows the past twenty year trend of the sales volumes for the top five steel makers.

	Arcelor mittal	POSCO	JFE	Bao Shan Steel	Nippon Steel
1991					
1992					24,277
1993					23,680
1994		10,366			25,511
1995	1,925	11,248			29,054
1996	1,859	12,041			30,894
1997	2,171	12,408		3,026	27,266
1998	3,492	9,836		3,329	25,111
1999	4,680	10,694		3,392	21,722
2000	5,097	12,189		3,717	24,180
2001	4,486	10,177		3,500	24,912
2002	4,889	11,514		4,060	20,676
2003	5,441	14,937	19,930	5,328	22,578
2004	22,197	20,964	21,944	7,034	25,955
2005	28,132	25,687	26,108	15,371	31,562
2006	58,870	27,075	27,404	20,252	34,550
2007	105,216	34,016	27,893	25,026	36,805
2008	124,936	38,669	31,080	28,705	42,381
2009	61,021	29,045	39,050	21,657	47,659
2010	78,025	41,433	30,673	29,832	37,611
2011	93,973	62,287	37,392	34,418	48,089
2012	84,213	56,493	40,132	30,304	51,848
2013	-	-	38,596	-	53,128

Table 4.43 Trend of the sales volumes for the top five steel makers[46]

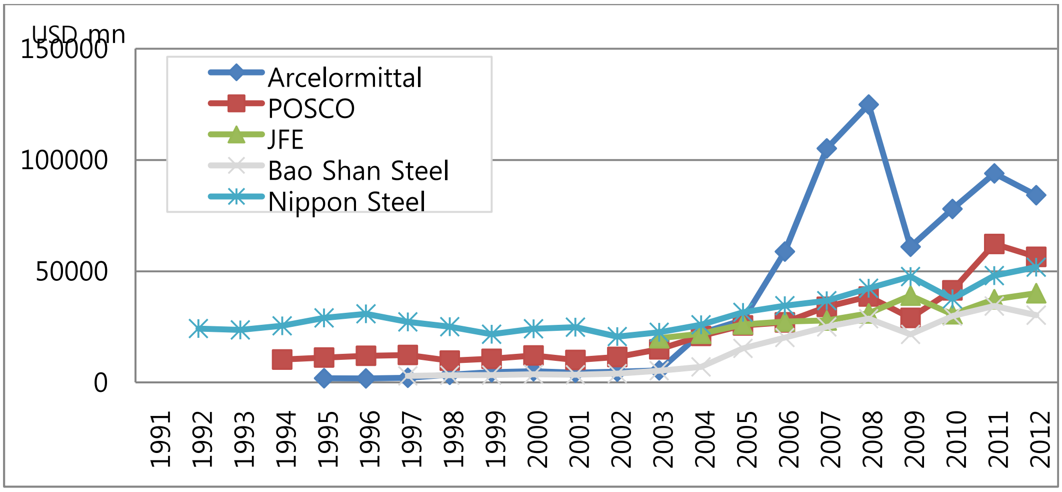

Figure 4.48 Trend of the sales volumes for the top five steel makers

46 http://www.bloomberg.com/markets/, POSCO annual report.

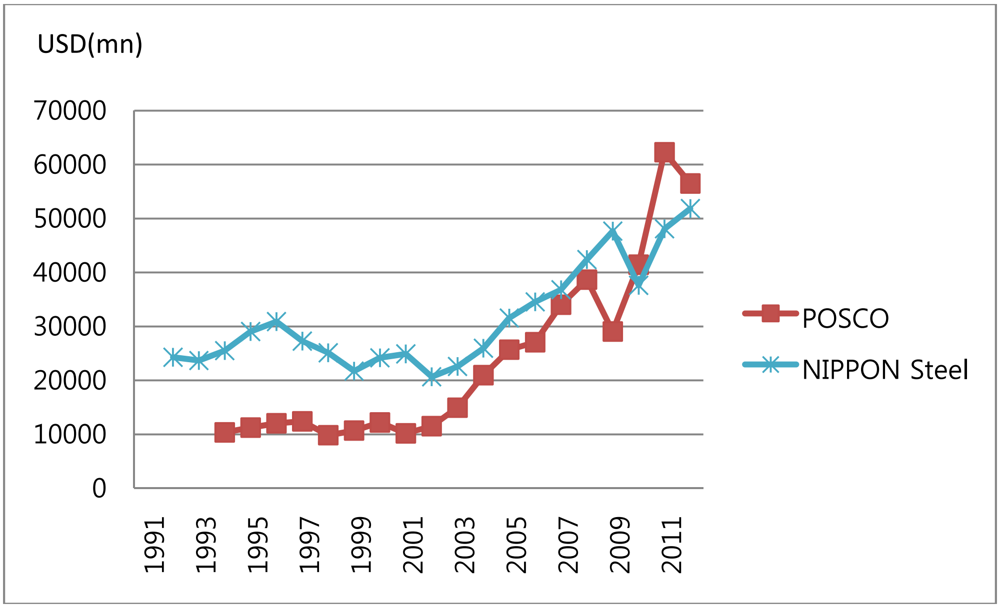

Figure 4.49 Trend of the sales volumes for POSCO and Nippon Steel

The sales volume of POSCO began to surge in 2002 and overtake that of Nippon Steel in 2010. As shown in Figure the sales revenue of POSCO did not reach half that of Nippon Steel until 1999. However, POSCO began to increase its sales revenue rapidly in 2000 and lead Nippon Steel in 2010 and 2011. During this period, the sales revenue of Nippon Steel increased steadily. However, POSCO produced greater strides.

3) Patent data and technological index analysis of POSCO and Nippon Steel

Figure 4.5 shows how the number of patents for POSCO and Nippon Steel in the US changed from year to year. POSCO had steadily filed about ten patents per year from the early 1990s. The accumulated number amounted to ninety-five in 2002. Most of these patents are related to new generation technologies of the steel industry such as FINEX steel making process.[47]

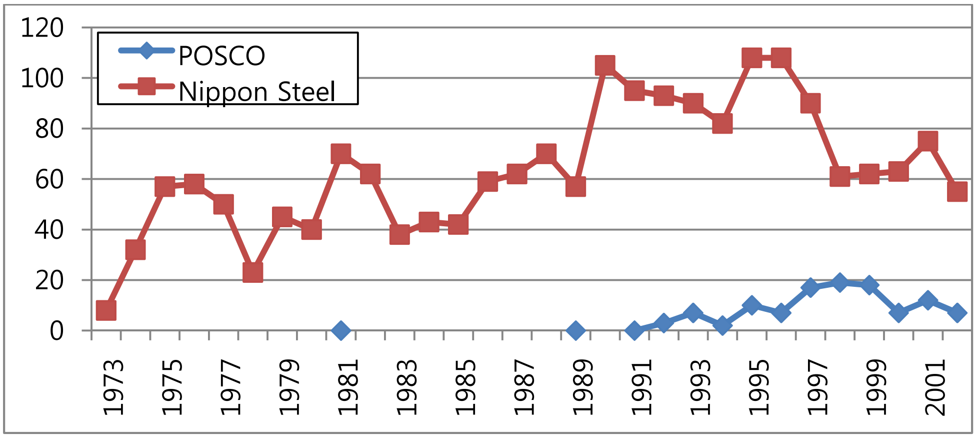

Figure 4.50 Number of patents for POSCO and Nippon Steel in the US[48]

The steel industry is based on a large scale mechanism industry. Therefore, a latecomer firm with up-to-date facilities sometimes shows a

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[47] Song, Sungsoo (2010). From COREX to FINEX: The Case Path-revealing Innovation in POSCO. KISTI, Knowledge Mapping and Its Use through Quantified Information Analysis, 2005

[48] Lee. Keun (2008). Economics of Catch-up

higher competitive edge than the leader.[49] This phenomenon is due to the difficulty of changing or upgrading the facilities of steel industry once they are completed. Accordingly, steel makers strive for growth through the innovation of technologies. However, they sometimes try to diversify their businesses and achieve economy of scale through mergers and acquisitions (M&A). The United States Steel Company is trying to diversify its business through the energy industry. Nippon Steel is also striving to diversify through advanced materials, biochemistry, service industry, and the electronics industry.[50] The patent analysis of Nippon Steel, which has tried to diversify its business, will reveal a wide variety of their patents. Knowledge Mapping and Its Use through Quantified Information Analysis[51] produced an analysis of the patents of POSCO and Nippon Steel in the US by using the data of the Wireless Intrusion Prevention System (WIPS). From 1993 to 2002 before the sales volume of POSCO surged, POSCO filed ninety-six patents in twelve technology areas. Half of the patents were concentrated on metallurgy. On the other hand, during the same period, Nippon Steel filed 792 patents in twenty-four technology areas, which amounted to twice that of POSCO.[52] Besides the areas of electronic components, optics, and information memory, Nippon Steel even filed in the areas of biotechnology, printing, and lightning. This seems to be related with Nippon Steel's business diversification effort.

The diversification made the weight of common areas appear small for POSCO and Nippon Steel. This made the analysis of the patents to

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[49] Chang, Strategic management in the age of global competition, 2007

[50] Chang, Strategic management in the age of global competition, 2007

[51] KISTI, 2005

[52] KISTI, Knowledge Mapping and Its Use through Quantified Information Analysis, 2005

compare POSCO and Nippon Steel quite difficult when using the method of this study for the analysis of catch-up among companies.

Accordingly, POSCO has tried to maintain its dominance in the steel industry rather than diversifying its business. In reaction to the threat of the latecomer firms, POSCO's dominance in the market seems to continue for a period by completing the facilities to produce 1.5 million-ton steel. POSCO globally commercialized the technology of FINEX for the first time.[53] The FINEX method is a new technology that cuts fifteen percent of the production costs. POSCO began to research the FINEX process in 1992 and completed the research in 2004.[54] This is in contrast with the failure of the CCF construction method of European companies and the suspension of *Direct Iron Ore Smelting* (DIOS) of Japan.

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[53] Song, Sungsoo (2010). From COREX to FINEX: The Case Path-revealing Innovation in POSCO. Chang, Strategic management in the age of global competition, 2007

[54] Song, Sungsoo (2010). From COREX to FINEX: The Case Path-revealing Innovation in POSCO. Chang, Strategic management in the age of global competition, 2007

Table is a second technological index for POSCO.

Indicator	Year	POSCO	Japan
Production yield rate (%)	1978	81	85
	1992	94.4	94.8
	1998	**94.7**	**89.1**
Man-hours Per tone (MH/tone)	1980	10.4	9.2
	1981	9.7	9.5
	1998	**2.7**	**4.1**
Energy Consumption (10^3kcal/tone)	1978	5,835	5,141
	1992	**5,290**	**5,890**
	1998	**5,220**	**5,780**

Table 4.44 Operating technology: POSCO vs. Japan

Sources: Korea Iron & Steel Association (Ed.) (2005, p. 169); Song(2002,p. 149), Song (2002, pp. 275-276) , Ki and Lee(2010)

First, POSCO's production yield rate[55] did not reach that of Nippon Steel in 1978. However, the production yield rate almost grew to the level in 1992. The production yield rate of POSCO in 1998 was much higher than that of Nippon Steel.

The indicator of Man-hours per Ton refers to the per capita productivity: the lower the number, the higher the productivity. In the early 1980s, POSCO lagged behind Nippon Steel. However, the indicator for 1998 shows that POSCO led Nippon Steel by a wide gap. The indicator of Energy Consumption per Ton shows the production efficiency with a specific amount of energy: the lower the number, the higher the efficiency. This indicator shows that POSCO had lagged

[55] The percentage of the production amount to the input of raw materials

behind Nippon Steel by a wide gap until 1978. However, POSCO overtook and widened the gap considerably in 1998. The synthetic analysis of these figures shows the accumulated technological capacity of POSCO. This result is similar in the previous three cases in that the technological catch-up preceded the catch-up in the market. The catch-up of POSCO in the market occurred in 2010. However, POSCO's technological catch-up occurred in the late 1990s in terms of the three technological indicators.

POSCO has tried to innovate its technologies since the operation of the first blast furnace in 1973. The chronological analysis of this is as follows. First, POSCO focused on the realization of the technologies it brought from advanced countries to the production sites in the 1970s, but did not consider its own invention of new technologies and technology systems. In this sense, POSCO's technological activities seemed to focus on the realization of existing technological systems and components. The evidence supporting this viewpoint is the percentage of high quality steel production. The percentage in 1978 amounted only to 2.5% in 1979.

POSCO's technological activities in the 1980s are similar to that in the 1970s. POSCO did not create any new technology systems, but POSCO is different in that it developed the components making up the technologies and invented its own technologies. In a nutshell, this period can be called the technology component innovation era. In the 1990s, POSCO in earnest caught up with Nippon Steel in terms of technology. In the 1990s, the technological activities of POSCO were centered on developing new-generation innovative steel technologies and expanding these innovations. The process called *Smelting Reduction* reduces the steel production costs by abridging the steel production process and includes various technologies such as DIOS and CCF in addition to

COREX, which POSCO chose. POSCO decided to introduce the method COREX, which an Australian company invented in 1985, and tried to commercialize COREX.

COREX refers to the steel production method of *Smelting Reduction*, which can use common coals and iron ores without any preliminary treatment unlike molten iron manufacture process, which use the existing blast furnaces.

Advanced steel makers overseas have promoted the invention of a new steel-making process that can replace the old method using blast furnaces. The environmental regulations have become strict and the amount of high-quality iron ores and coals reduces environmental hazards. The representative method is the process of *Smelting Reduction*. The COREX method, which skips the preliminary making process of coke and sintered ore and makes molten metal smelting the low-priced common coals and iron ores, can reduce production costs by fifteen percent by skipping the mid-process and using low-cost materials when compared to the existing method using blast furnaces.

The COREX method can also prevent air pollution by removing the dust and noxious gases occurring in the making process of coke and sintered ore. In addition, the COREX method enables steel makers to adjust output, which helps them to cope with the change of the steel market. For this reason, leading steel makers at that time were trying to invent the technologies competitively.

POSCO made an agreement with VAI in Australia. VAI has the source technologies for the introduction of the technology and embarked on the construction of COREX facilities in November 1993 for the purpose of growing into the world-leading steel maker through the commercialization of the *Smelting Reduction* method. Geoyang Construction Company, the present-day POSCO Engineering &

Construction Company, Ltd., was in charge of the construction. About 280 billion Korean Wons were invested. Geoyang Construction Company completed a new iron-making plant with a production capacity of 600,000 ton by applying the *Smelting Reduction* method on November 28, 1995, which was called new-generation innovative iron-making technologies. The facilities were the second largest to those of the Pretoria Steel Plant of Iscor in South Africa. However, steel makers worldwide gave attention to the successful operations of the facilities because they were the first large-scale commercialized facility with economy of scale.

Like this, POSCO in the 1990s began to develop the mid-completion stage technologies in which advanced countries could not come to fruition, and thus made a few precedents. In this regard, POSCO’s technological activities in the 1990s climbed over the stage of developing components of technologies, entering the technology invention stage and leading the technological activities in the world steel industry. POSCO aggressively participated in the activities to improve their operation technologies in the area of iron making, steel making and rolling in addition to developing the technology systems.

POSCO has its own internal R&D center called the Research Institute of Industrial Science and Technology (RIST). The research center was founded in 1987 based on a fund, the total amount of which POSCO donated. RIST actually plays the role of an internal outsource research center by executing an interchange of personnel. The trend of POSCO’s patents and the establishment of an internal R&D center are similar to those of the aforesaid three catch-up cases. The answer and finding 1 from the three cases that accumulated technological capabilities is the base of catch-up in the market and can be applied to the POSCO case study.

In summary, POSCO has made a lot of effort to accumulate technological capacities by using different methods according to the times since establishment. POSCO has led Nippon Steel in the various technology indicators that this paper has cited. Based on the accumulated technological capacities, POSCO has increased sales revenue. POSCO's catch-up with Nippon Steel in the market occurred in 2010 and the technological catch-up occurred in the late 1990s considering the above three technology indicators. Like the cases of Huawei vs. Ericsson, Samsung vs. Sony, and Hyundai vs. Mitsubishi, the technological catch-up precedes the catch-up in the market according to the analysis of companies which succeeded in the catch-up by the leaders.

4) The quality of patents (Average citations received by POSCO and Nippon Steel Corporation)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
POSCO	2.00	5.00	5.33	7.67	2.90	4.80	4.77	2.56	3.58	3.00	6.08	2.47	1.43	3.20	1.00	0.32
NIPPON	9.06	10.01	11.77	15.86	9.63	9.07	7.70	8.30	5.69	4.75	3.73	3.27	3.31	2.35	1.75	1.21

Table 4.45 The quality of patents (Average citations received by POSCO and Nippon Steel Corporation)

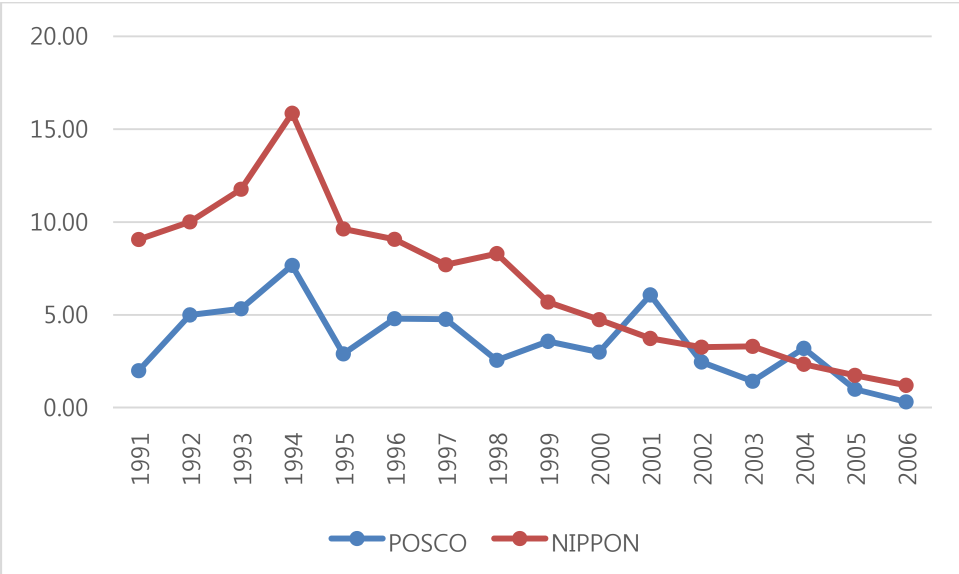

Figure 4.51 The quality of patents (Average citations received by POSCO and Nippon Steel Corporation)

The quality of two firms' patents can be measured by the average number of received, because the more a patent is cited, the more it is considered to be of value or worthy of use (Albert et al., 1991).Figure above provides average received citations of the two firms' patents. The trend shows that the gap of the patent quality of the two firms has been narrowing. POSCO caught up with Nippon Steel Corporation in 2001 and 2004 and consolidated its positions until 2006.

5) The reasons for the lack of patents in the technological catch-up of POSCO

The analysis of patents through the technological indicators shows the fact that the process of catch-up is different between the IT sector with frequent generation change and the non-IT sector with infrequent generation change. That is, the catch-up patterns are different from each other. However, within the same non-IT sector with infrequent generation change, the processes of catch-up of POSCO and Hyundai are different. The catch-up process of Hyundai is revealed in its patents. In terms of patents, the technological catch-up precedes the catch-up in the market. On the other hand, as the below figure shows, the accumulation process of technologies is not revealed in patents because the steel industry has its own unique characteristics even though the steel industry belongs to the same non-IT sector. The automobile and steel industries both require large scale facilities. Also, the weight of tacit knowledge is greater for both industries. However, the technological outcome does not reveal itself in the patents for the steel industry compared to the automobile industry. The reason for the lack of patents in the steel industry is that the steel industry sector has its own unique characteristics as follows.

First, the effect of economy of scale is greater in the steel industry, which centers on the equipment.[56] Accordingly, the equipment and the size of the facilities are more important in the steel industry than in the automobile industry. The production costs of the steel industry tend to decrease rapidly as the size of production unit increases. Especially, the integration of iron making, steel making, and rolling into one process can

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[56] Song, 1999

reduce the transport costs and the operation time.[57] The optimal size of an integrated steel mill is known to be 6 to 12 million ton based on the output of crude steel.[58] The size of 9 to 12 million ton for the POSCO plants can be optimally assessed. The automobile industry also has economy of scale, but the variety of products is not as simple. Thus, the size of the facilities plays an important role in the steel industry. Patents show themselves in the innovation of products or production processes, but cannot exactly measure the technological capacities.

Also, the facilities are difficult to replace within twenty years once they are installed in a steel-making plant.[59] Therefore, the technological activities of the steel makers depend on the nature of the production facilities. Thus, it is not too excessive to suggest that the choice of the production facilities determines its success.[60] Accordingly, the technological activities do not reveal themselves in the patents.

The second reason for the lack of patents in the steel industry is the continual operation. The stoppage of ignited blast furnaces in the steel mill incurs a lot of loss in production. Therefore, once the process starts in the steel mill, it is difficult to change the facility even if a new process of steel making emerges. Accordingly, the heavy weight of tacit knowledge is common in both the automobile and steel industries. However, the innovation of facilities cannot be applied to the steel industry before a new blast furnace is built, which makes it difficult to apply innovative patents for technologies to the steel industry compared to the automobile industry.

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[57] Jonghyeon Nam, 1979

[58] Cockerill, 1974

[59] Song, 1999

[60] Song, 1999

The third reason for the lack of patents in the steel industry is the continuity of the steel making process. All the related manufacturing processes should be in harmony with each other in the steel industry because they are all connected continuously. A defect in one process produces a defect in other processes, which leads to fatal loss (Song, 1999). Therefore, a new process is difficult to introduce into a part of the entire processes, which is another reason why the steel industry's technological development does not reveal itself in patents.

The fourth reason for the lack of patents in the steel industry is that the innovative technologies in the core processes in the steel industry are led by a few steel engineering companies and facility manufacturers. The core process technologies also change about every ten years.[61] Thus, the innovation of the technologies is difficult to measure.

In summary, the patterns of technological innovation are different within the same non-IT sector. The outcome of accumulated technological capacities of the automobile manufacturers shows itself in products and within the manufacturing processes and facilities. However, the technological capacities of the steel industry are centered on the "facilities." Generally, the innovation of products mostly reflects the patents, followed by the manufacturing processes. On the other hand, the improvement of equipment or the technological development of facilities is not well expressed in the patents. The chance for the reflection is also low.

[61] Song, 1999

Chapter Five
Answers to the research questions and possible patterns of technological catch-up process from the four cases

We conducted patent analyses in various perspectives about the catch-ups of Huawei with Ericsson, Hyundai with Mitsubishi, Samsung with Sony, and POSCO with Nippon Steel in chapter four. Chapter five will attempt to find answers to the research questions that are raised in Chapter two and Chapter five and will examine whether there is an existence of possible patterns occurring in the catch-up process. We attempt to look for possible patterns through comprehensive understanding of the in-depth data of patent analyses in Chapter four.

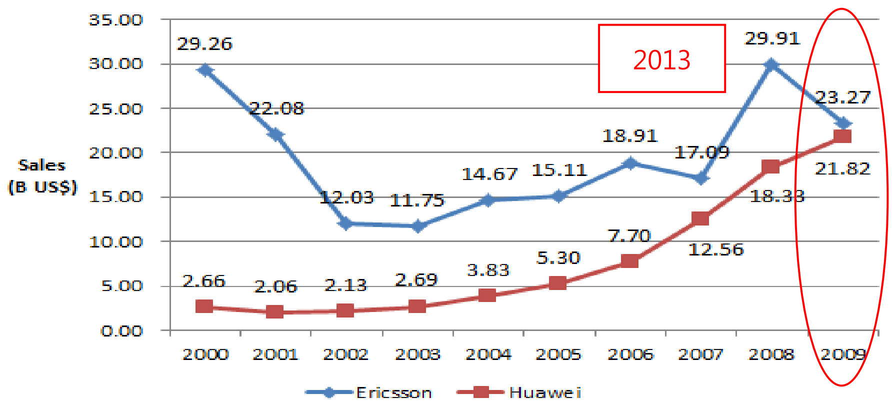
Through a review of previous studies, our study specified the question of "What happened in the process of catch-up at the firm level?" into the following four research questions:
1) Can a latecomer catch-up with the forerunners in the market without technological capabilities? 2) If a latecomer could catch-up with the forerunners in the market based on technological capabilities, is the catch-up from similar or different technologies? 3) Is it necessary to invest in cutting-edge or more recent technologies for a catch-up? 4) Did science-based technologies for the latecomer increase over time to accelerate a catch-up? We will suggest possible answers and findings in the order of the research questions.

Research question1

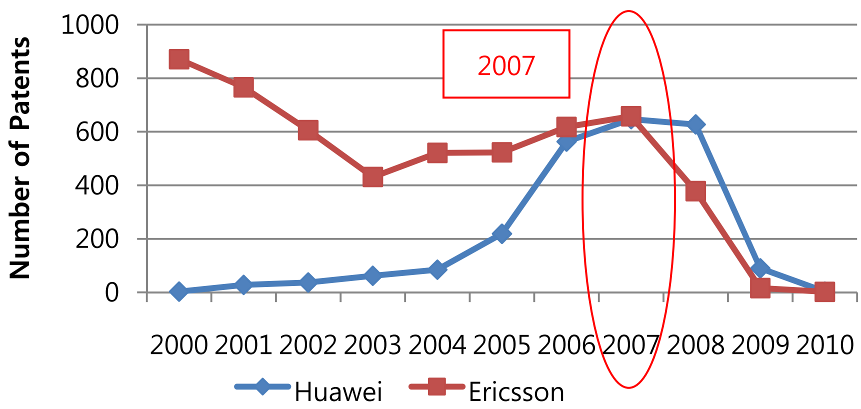
: Can a latecomer catch-up with the forerunners in the market without technological capabilities?

The following findings are the points of time in the catch-up in sales revenue and technology based on the analyses for the cases discussed in Chapter four.

CASE1) Huawei vs. Ericsson in Telecommunication Equipment industry

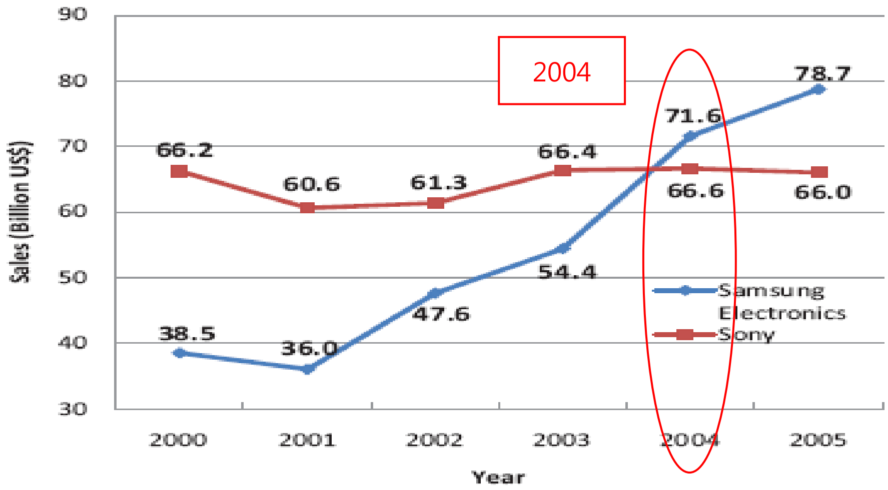


Sales of Ericsson and Huawei

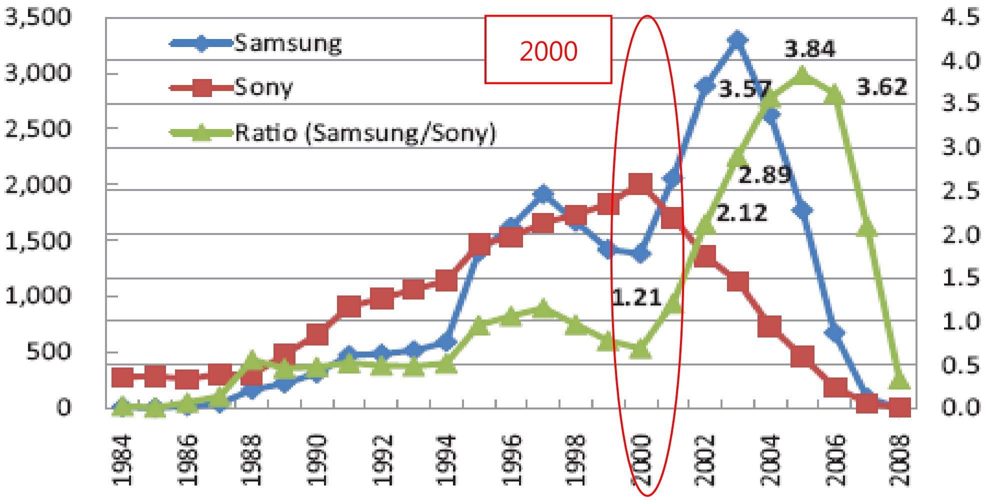


Technology Quantity (Number of patents)

Case2) Samsung vs. Sony in Electronic industry



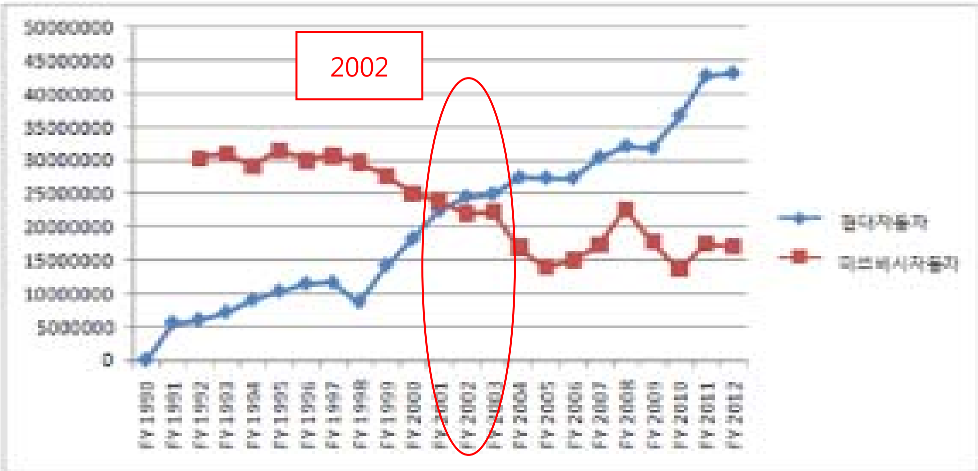
Sales of Samsung and Sony (Joo&Lee, 2010)



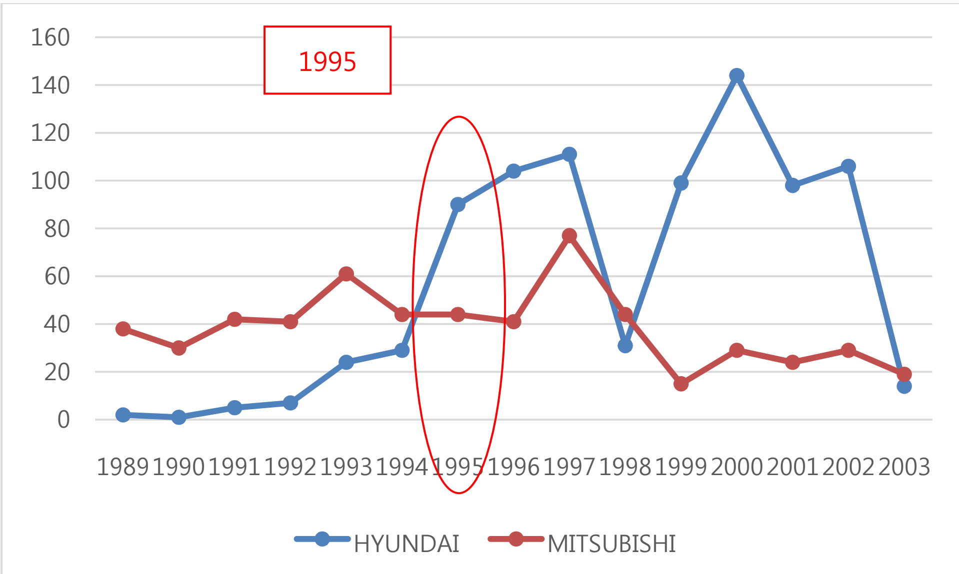
Number of patents held by

Samsung Electronics and Sony (Joo&Lee, 2010)

Case3) Hyundai Motors vs. Mitsubishi Motors in Automobile industry

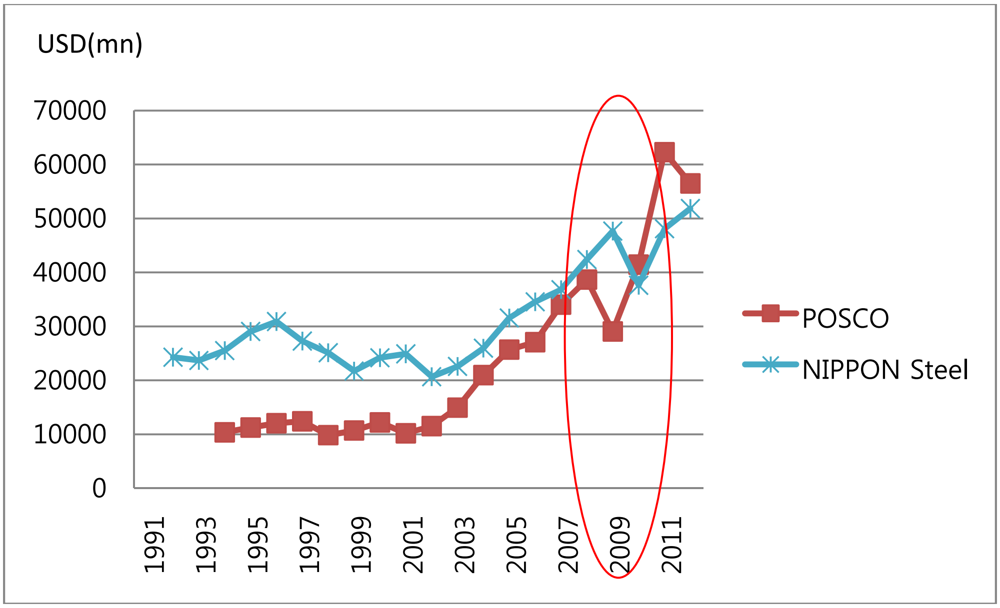


Sales of Hyundai Motor and Mitsubishi



Technology Quantity (Number of patents)

Case 4) POSCO vs. Nippon Steel Corporation in Steel industry



Trend of the sales volumes of POSCO and Nippon steel

Indicator	Year	POSCO	Japan
Production yield rate (%)	1978	81	85
	1992	94.4	94.8
	1998	**94.7**	**89.1**
Man-hours Per tone (MH/tone)	1980	10.4	9.2
	1981	9.7	9.5
	1998	**2.7**	**4.1**
Energy Consumption (10^3kcal/tone)	1978	5,835	5,141
	1992	**5,290**	**5,890**
	1998	**5,220**	**5,780**

Operating technology: POSCO vs. Japan

Sources: Korea Iron & Steel Association (Ed.) (2005, p. 169); Song(2002,p. 149), Song (2002, pp. 275-276) , Ki and Lee(2010)

Figures above shows the point of time (2013) for Huawei's catch-up with Ericsson in sales revenue, and the technological catch-up point (2007). Samsung's sales revenue catch-up with Sony occurred in 2004. The technological catch-up of Samsung with Sony occurred in 1994. The Hyundai sales revenue catch-up with Mitsubishi occurred in 2002. The technological catch-up of Hyundai with Mitsubishi occurred in 1995. Lastly, the POSCO sales revenue catch-up with Nippon Steel occurred in 2009. The technological catch-up of POSCO with Nippon Steel occurred in 1998.

We found the following certain fact that is true for the four cases by synthesizing the results of the patent analysis. Huawei, Samsung, Hyundai and POSCO already accomplished a catch-up in their respective sectors and they are from developing countries. Until recently, these four cases are the only catch-up examples for the four sectors. In this context, the finding 1 below is not only a finding applied to the four case studies. Answer and finding 1 below can be a catch-up pattern when considering all catch-up cases until now.

Answer and finding 1
: Latecomer's technological catch-up tends to precede catch-up in the market.

The common point for the four cases is that the latecomer overtook the leading firms in technological capacities. The latecomers also maintained their dominance. The technological catch-up occurred more than five years earlier than the overall catch-up in the market. Therefore, we can conclude that the technological capacities are the bases of the catch-up. The latecomers produced accumulated technological capacities as a stepping stone for the catch-up in the market.

The above analyses suggest that the catch-up in the market occurs after the technological catch-up. The analyses suggest that the accumulated technological capabilities are the key to catch-up in the market success. The technology alone cannot lead to market success. Although various components such as entrepreneurship, marketing strategy or globalization strategy lead to success in the market, accumulated technological capabilities, which we deal with in this paper, is the main factor for the catch-up in market success.

Some may question that the accumulated technological capabilities are the base of catch-up in the market by pointing out the possibility of different cases other than the four cases aforesaid. A counterargument we expect is that latecomers overtake the leading firms through mass-production, which is based on low-cost labor and is a strong point of developing countries without technological capabilities. This paper intends to demonstrate through two cases that it is not so easy to catch up with the leading firms without technological capacities. A short-lived market success without technological capability is well manifested by South Korea's Daewoo Motors and Malaysia's Proton (Proton Holdings Berhad). Daewoo and Proton lost market share in the automobile industry.

The case of Daewoo Motors

In 1972, Daewoo Motors (hereafter, Daewoo) signed a technological alliance with General Motors Company (GM). Until the mid-1990s, major core technologies were transferred from GM to Daewoo in the form of a joint venture. (Lee & Lim, 2001)

Daewoo initiated a scale expansion through the building of automobile parts assembling factories in Eastern Europe, Asia and Uzbekistan in 1993, taking advantage of low-cost labor. Daewoo mainly focused on cost competitiveness rather than quality differentiation (Lee & Lim, 2001). Daewoo eventually filed for bankruptcy in August 1999. This is in contrast to Hyundai who heavily invested on R&D and built in-house R&D centers to develop its own engine.

The case of Proton

In 1983, Proton forged a technological alliance for production with Mitsubishi and Citroen. Proton pursued a technological alliance and mergers and acquisitions (M&A) to win the market instead of developing its own technology. However, Proton's management recently started to falter in market share, plummeting from seventy-four percent[62] to thirty-two percent.[63] The Daewoo and Proton cases illustrate the importance of building technological capabilities to catch-up with the leading companies. Proton failed to reform independently through innovation and focused on low-cost production.

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[62] New Straits Times. 9 July 1995. Retrieved March 21, 2013.

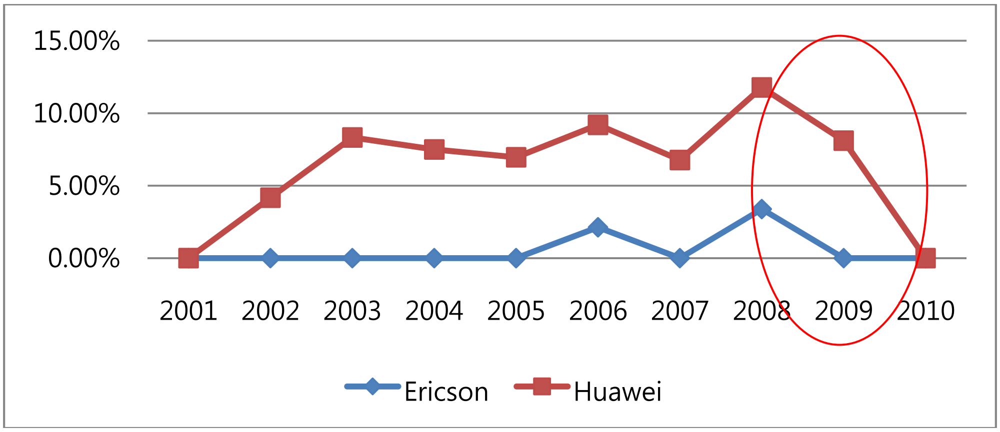
[63] Malaysia's Proton loses top-selling spot for the first time. Malaysia Today. Archived from the original on 10 October 2007. Retrieved February 28, 2007.

Research question 2

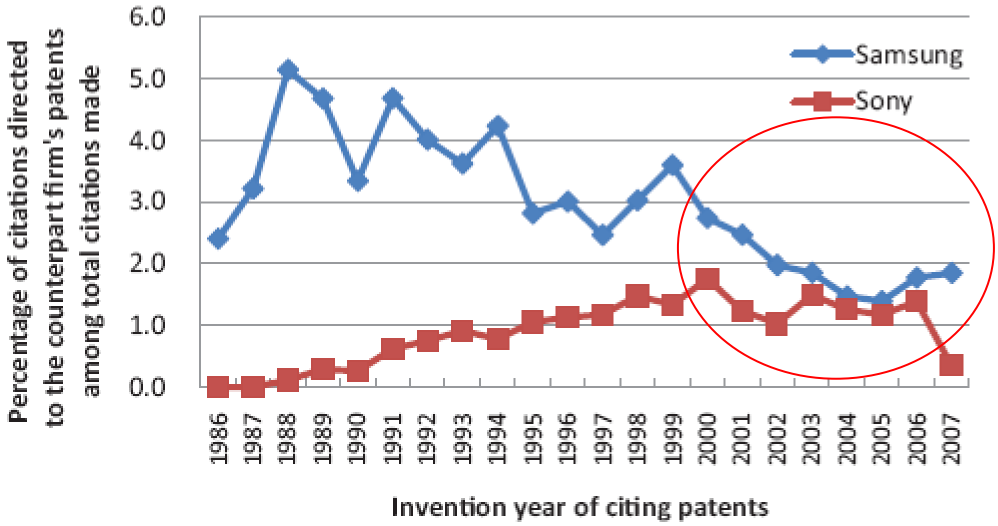
: If a latecomer could catch-up with forerunners in the market based on technological capabilities, is the catch-up from similar or different technologies?

We mentioned in Chapter two that we have to make an overall judgment to verify whether the catch-up is from similar or different technologies, considering the level of technological dependence between the two firms, self-citation ratio of the latecomer and the number of received citations for each patent.

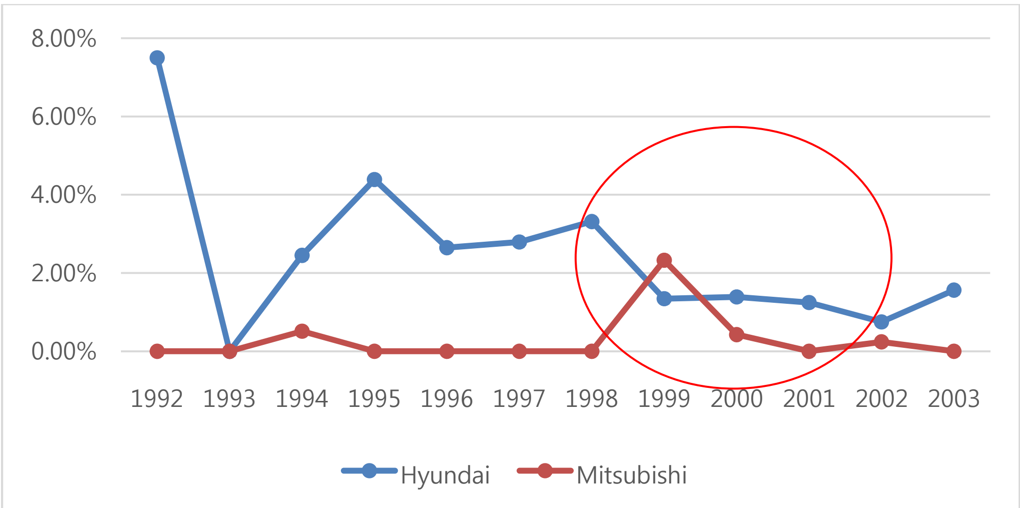
First, we examine the level of technological dependence between the two firms. The trend for all cases shows that fast followers have acquired more independence from the incumbents.



The share of citations directed to the counterpart firm's patents



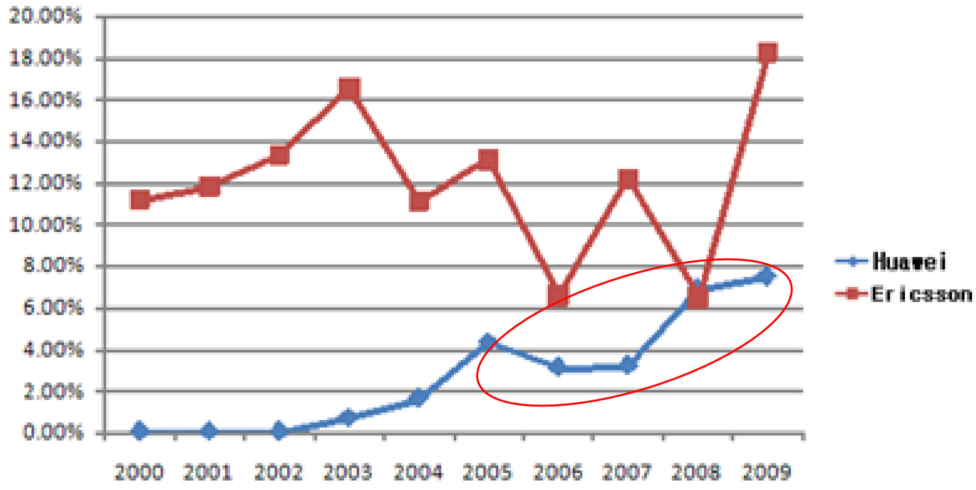
The share of citations directed to the counterpart firm's patents.(Joo&Lee,2010)



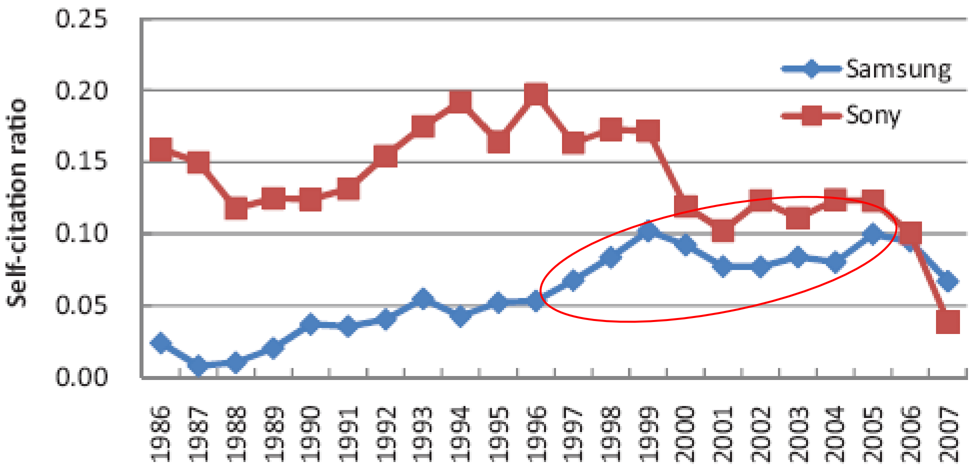
The share of citations directed to the counterpart firm's patents

Second, we investigated the self-citation ratio of the latecomer.

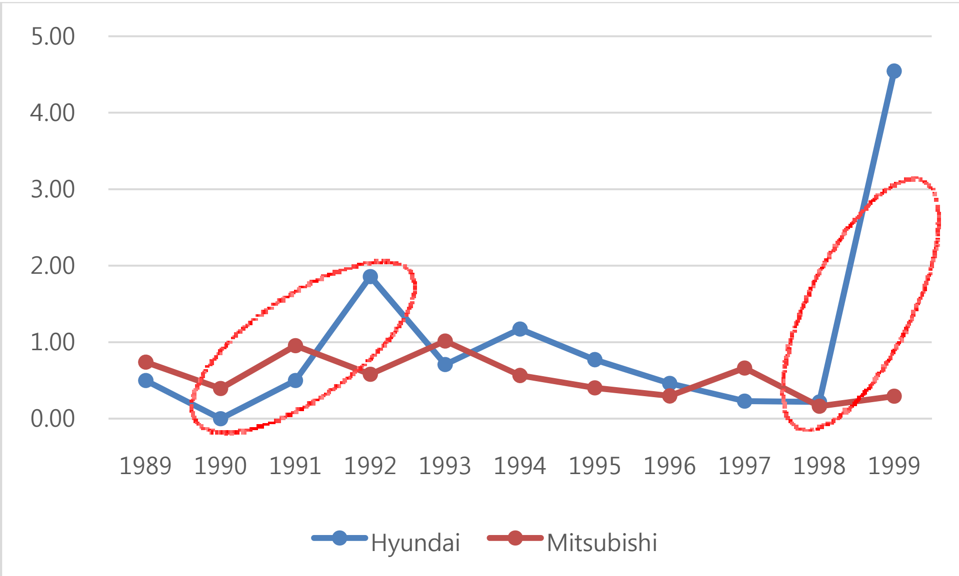
The trend for all cases showed that the latecomer's self-citation ratio is increasing.



Self- Citation Ratio of Huawi and Ericsson



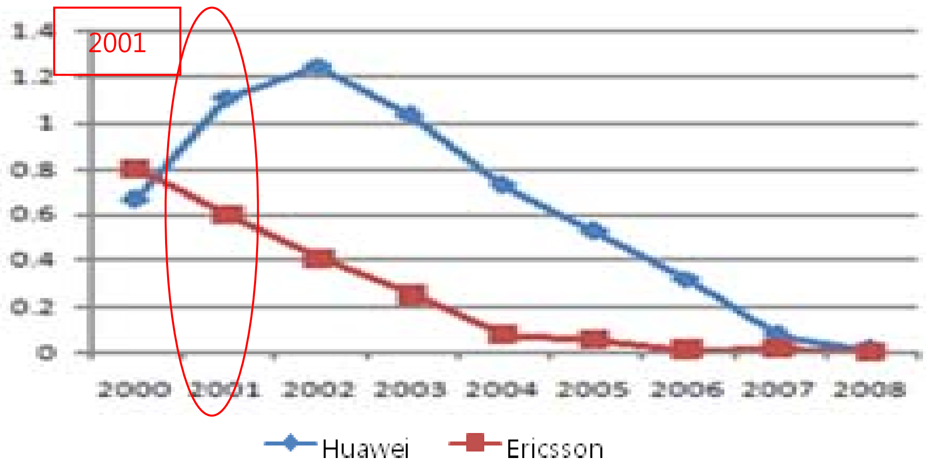
Invention year of citing patents(Joo&Lee,2010)



Self-citation ratio of Hyundai and Mitsubishi

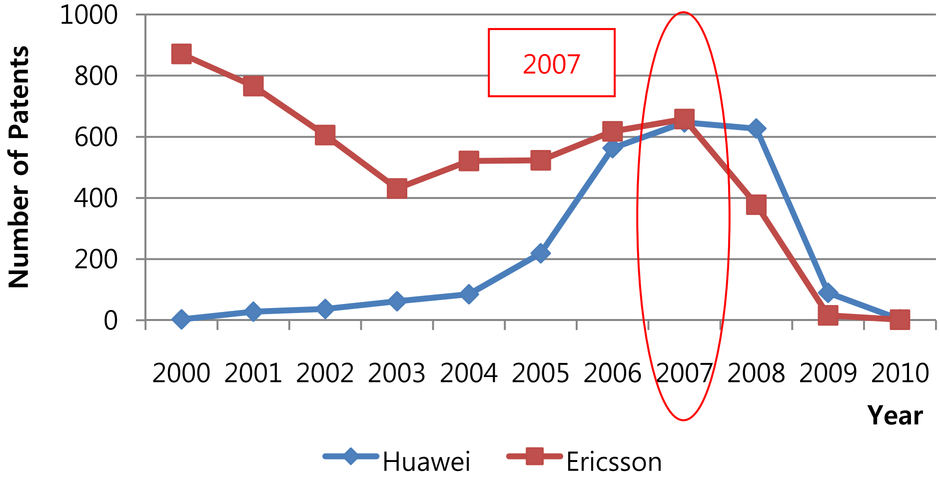
Third, we investigated the number of received citations for each patent.

Case 1) Huawei vs. Ericsson in Telecommunication Equipment Industry



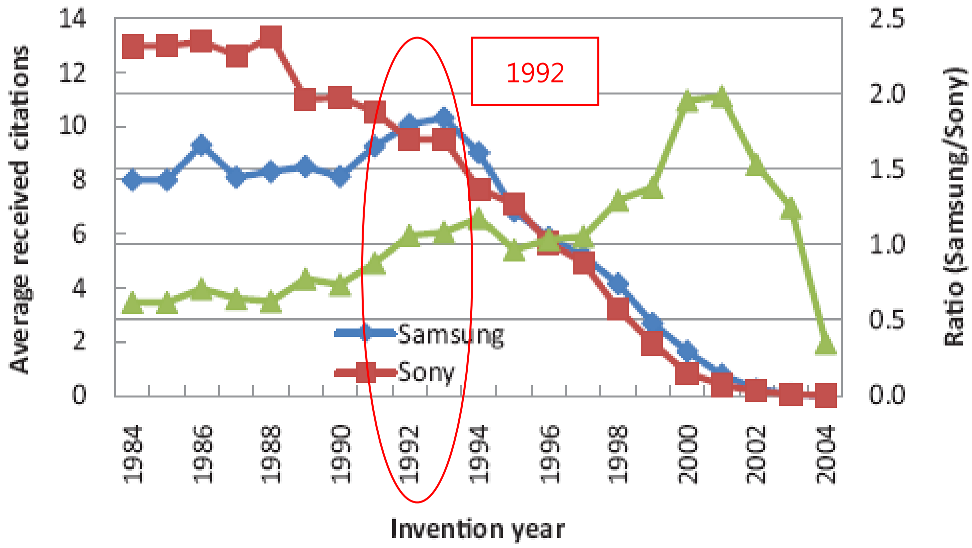
Average number of citations received

(Qualitative technological catch-up)

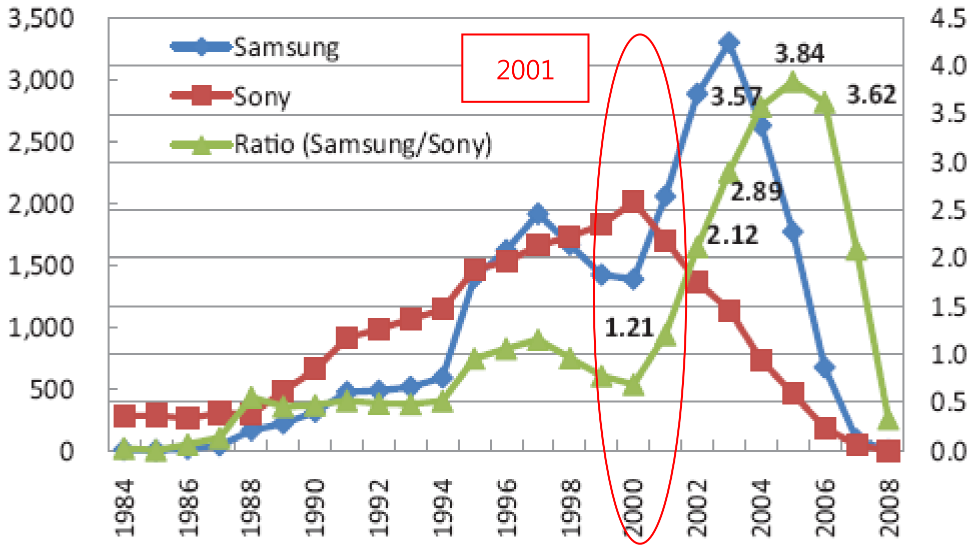


Number of patents (Quantitative technological catch-up)

Case2) Samsung vs. Sony in Electronic industry

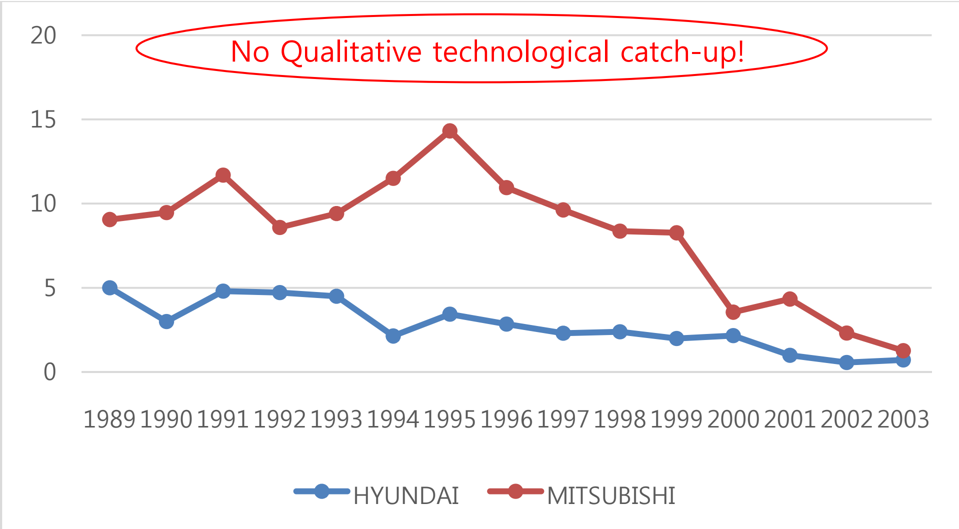


Average citations received by Samsung Electronics' and Sony's patents(Joo&Lee,2010)



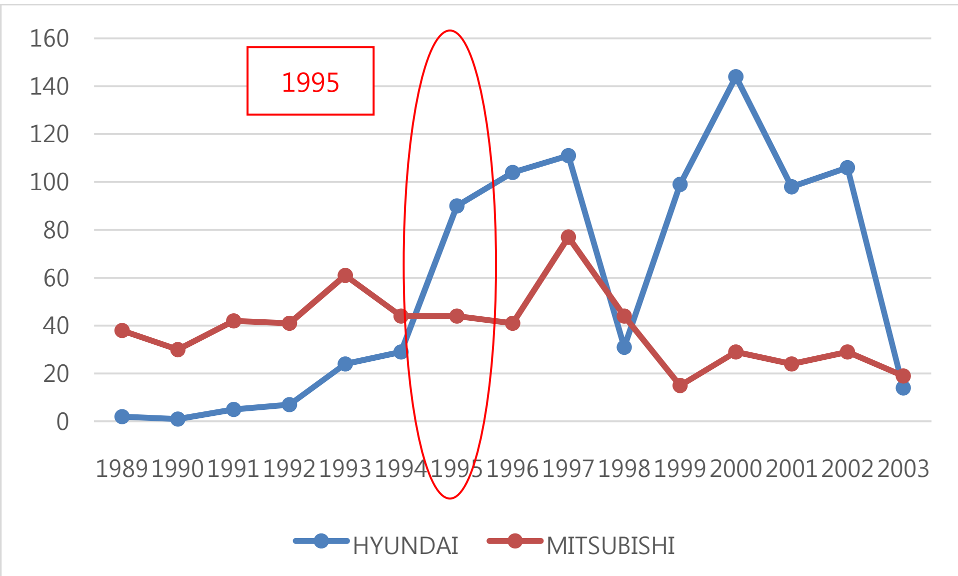
Number of patents held by Samsung Electronics and Sony (Joo&Lee, 2010)

Case3) Hyundai Motors vs. Mitsubishi Motors in Automobile industry



Average number of citations received

(Qualitative technological catch-up



Number of patents (Quantitative technological catch-up)

The orders of qualitative and quantitative technological catch-up are the same in the cases of Huawei vs. Ericsson and Samsung vs. Sony, all of which are in the information and communications technology (ICT) sector. Huawei overtook Ericsson in qualitative terms in 2000, in which Huawei began to file patents related to communications equipment. Huawei has led since. In quantitative terms, Huawei began to lead Ericsson in 2007 and has had dominance over Ericsson since.

Samsung began to lead Sony in terms of the patents in 1991. Samsung has maintained dominance. In quantitative terms, Samsung also began to lead Sony in 1994 and has led Sony since.

In contrast, in the case of Hyundai and Mitsubishi in the automobile industry, Hyundai overtook Mitsubishi in quantitative terms in 1995. Hyundai maintained dominance except in 1995 when the IMF financial crisis occurred. Surprisingly, in terms of patent quality, Hyundai has failed to overtake Mitsubishi. This case shows that the technological nature of each sector can demonstrate a difference in the points of time when technological catch-up happens in terms of quantity and quality.

A new technological generation change provides a new window of opportunity for latecomers to emerge. A repeated generation change occurred in Digital TV, Flash memory, D-Ram and the liquid-crystal display (LCD) sectors. Thus, timely decision making in investment is very important. In the period of technological generation change, Samsung and Sony chose a different path.

In the sectors with frequent generation change, the technology cycle is short. Timely decisions have to be made due to the high uncertainty caused by unstable technological trajectory. Even the leading firms have difficulty in predicting the future. In this sector, latecomer firms can succeed when the windows of opportunity opens. That is, they can catch up with the leaders by investing a huge amount of resources into emerging technologies when a technological paradigm shift occurs. In this case, the latecomer's qualitative technological catch-up can occur and sometimes the qualitative technological catch-up point of time precedes the quantitative catch-up point of time. While emerging technology is widely being adopted in the market and slowly recognized as mainstream technology, the technology can become the source and core technology for a generation in the sector as time goes by. If a latecomer in a sector with frequent technology generation change invested in emerging technology that will be rising in the near future considerably at the crossroad of generation change and finally succeed, the qualitative technological catch-up can occur.

This result is related to the fact that in a sector with repeated generation change, the latecomer has a higher possibility of catch-up with the market leader in new technology domains.

In conclusion, after making an overall judgment when considering the level of technological dependence between the two firms, the self-citation ratio of the latecomer and the number of received citations of a patent, the latecomer firm catch-up occurred with the forerunner with different technologies of its own. This reflects that there is something different with the latecomer firm that succeeded to accomplish the catch-up. Thus, the answer to question number two is the following..

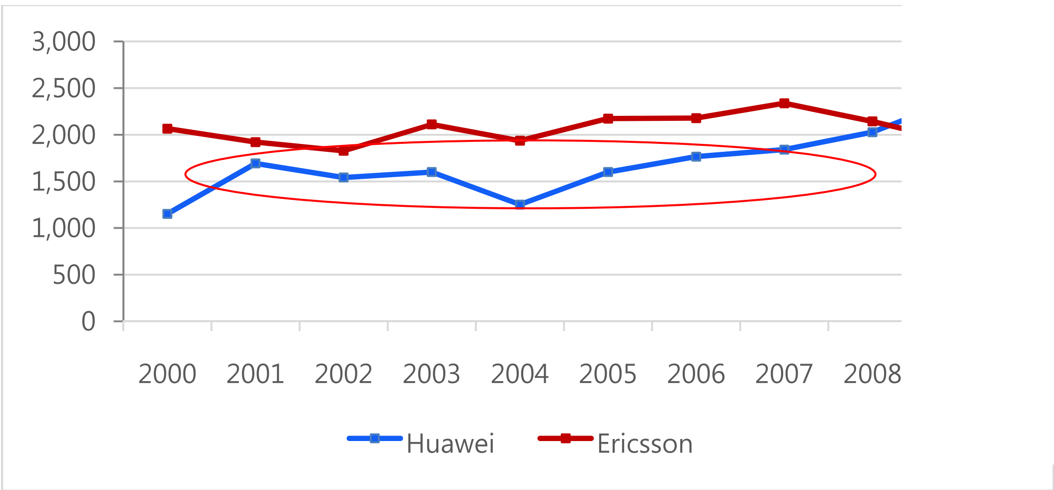
Answer and finding 2

: Latecomers tend to catch-up by using technologies that differ from those employed by incumbents.

Research question3
: Is it necessary to invest in cutting-edge or more recent technologies for a catch-up?

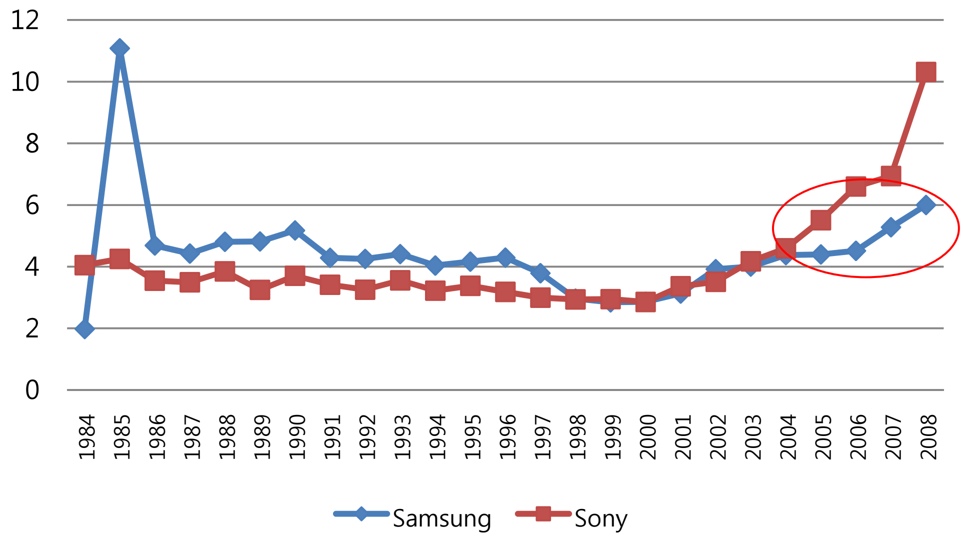
The following is the result of a case-by-case analysis of backward-citation lag for the three cases in chapter four. The result shows the obvious differences among the industrial sectors. The analysis of the backward-citation lag between Huawei and Ericsson reveals that Huawei has focused on developing up-to-date technologies since 2000. Huawei began to file patents related to communication equipment. During the ten year process, Huawei has gained a foothold over Ericsson by using up-to-date technologies.

Case1) Huawei vs. Ericsson in Telecommunication Equipment Industry



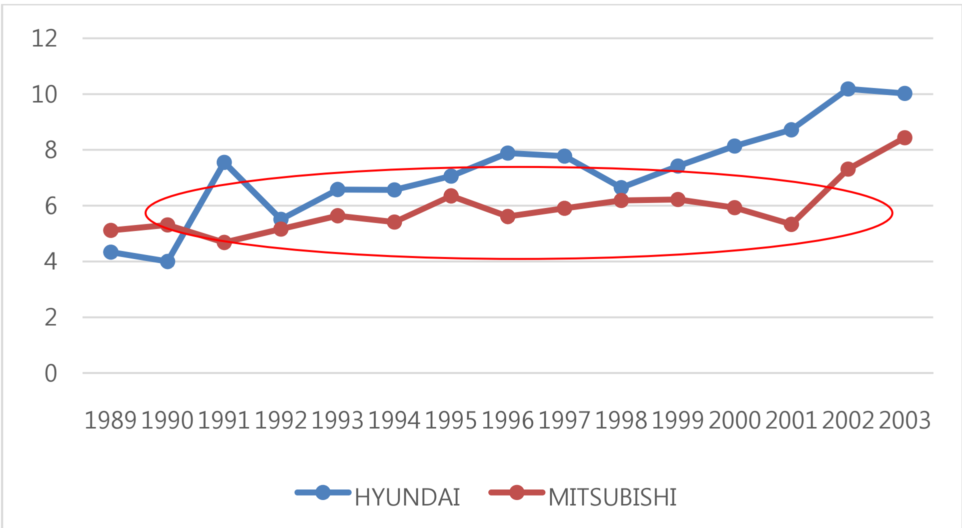
Backward Citation Lag

Case2) Samsung vs. Sony in Electronic industry



Backward Citation Lag

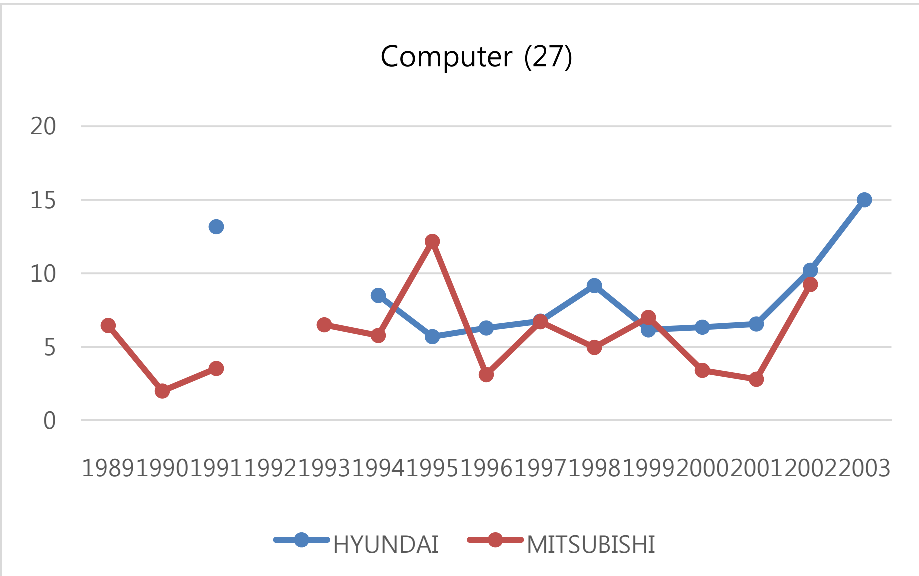
Case3) Hyundai Motors vs. Mitsubishi Motors in Automobile industry

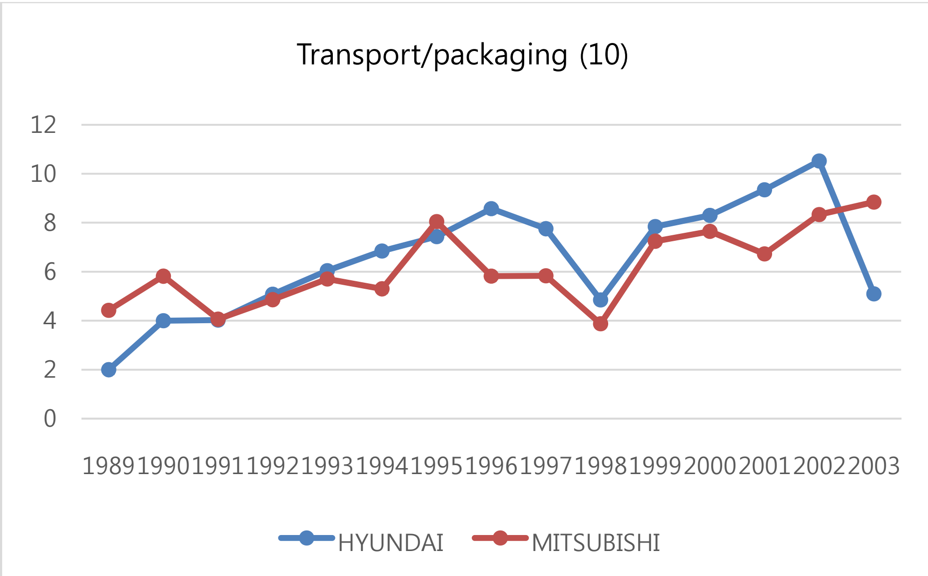


In the backward-citation lag of Samsung and Sony, Samsung overtook Sony in 2005. Samsung has maintained dominance since. This shows that Samsung has used more up-to-date technologies since 2005.

In contrast, the comparison of backward-citation lag between Hyundai and Mitsubishi shows that Hyundai failed to overtake Mitsubishi. This results from the influence of a technological regime within sector and especially the length of the technology cycle.

The analysis of the backward-citation lag of Hyundai and Mitsubishi in each technological field in chapter four is as follows.





The analysis shows that Hyundai has used more up-to-date technologies than Mitsubishi only in the areas of computers and transportation. However, Hyundai's overall technologies except for those two areas do not show this trend.

Many major newspaper articles and the press reported that electric and smart cars would lead the new generation change in the automobile industry. In light of this, the analysis of the above patent data shows that Hyundai predicted the generation change of smart cars and has acquired the related technologies. Therefore, the analysis of backward-citation lag of Hyundai and Mitsubishi in each technological section shows the catch-up case of Hyundai with Mitsubishi and confirms the fact that up-to-date technologies are utilized in the sector with frequent generation change of technology.

Answer and finding 3
: Whether a latecomer can succeed in a catch-up with a forerunner by relying on more recent technology depends on the sector's technological nature, and especially the length of the technology cycle.

A summarized conclusion from findings 2 and 3 is that Huawei, which belongs to the ICT sector, overtook Ericsson by using better and more up-to-date technologies in terms of patent analysis. We observed the same phenomenon in some technological areas as computer and transportation in the Hyundai and Mitsubishi case.

This conclusion reflects that latecomers during the catching-up process depend on more recent technologies in the sector with a short technological cycle and frequent generation change. Conversely, latecomers in the sector with less frequent technological generation change gradually tend to improve the existing technologies in a different way from the incumbents rather than invest in up-to-date technologies.

Research question 4

: Did science-based technologies for the latecomer increase over time to accelerate a catch-up?

The following is the result of an analysis of science-based citations in the three cases in Chapter four.

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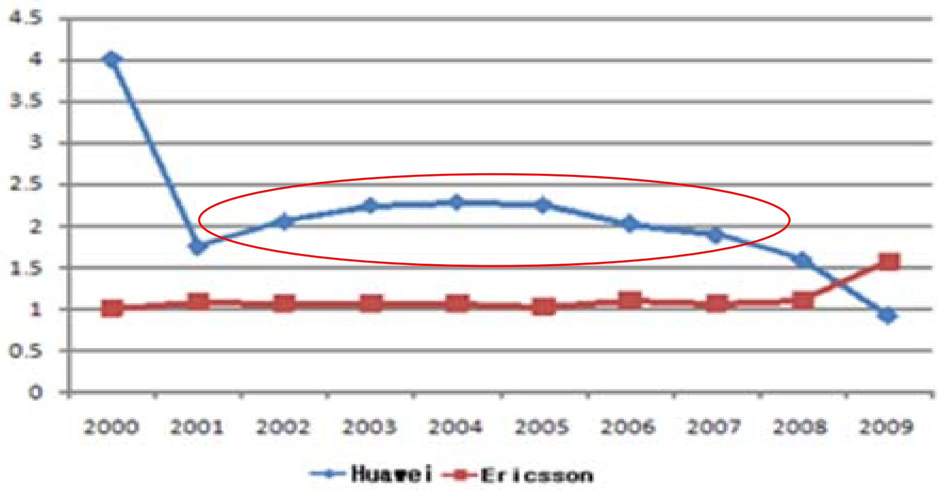
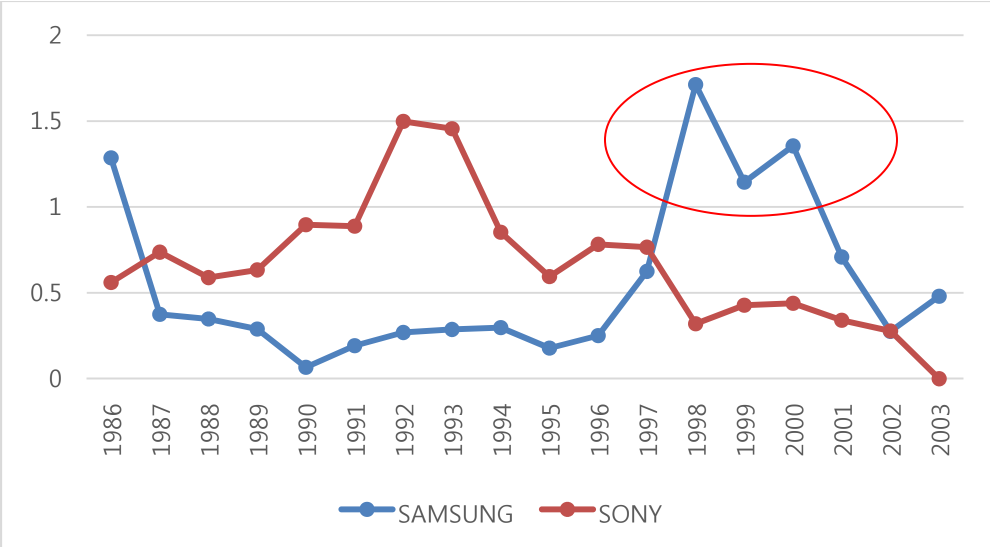
Case1) Huawei vs. Ericsson in Telecommunication Equipment Industry



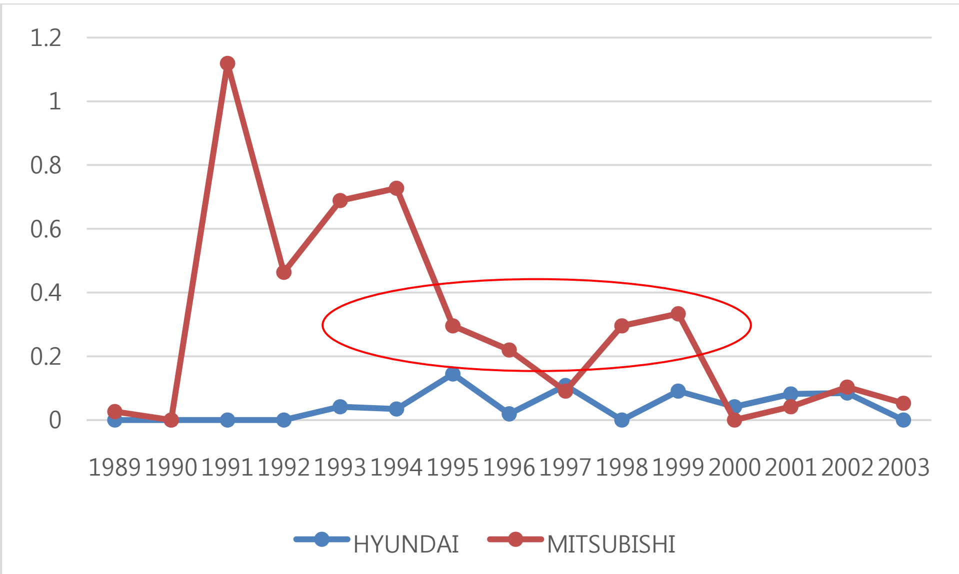
Citation to Non-Patent Literature as Science-Base

Case2) Samsung vs. Sony in Electronic industry



Citation to Non-Patent Literature as Science-Base
(electronic & communications)

Case3) Hyundai Motors vs. Mitsubishi Motors in Automobile industry



Citation to Non-Patent Literature as Science-Base

The trend of science-based citation shows that Huawei has led Ericsson constantly and that Samsung continued to give more weight to science-based citation and has overtaken Sony since 1999. However, Hyundai Motors has not overtaken Mitsubishi in science-based citation.
So, the answer to the question number four is like the blow.

Finding 4
: Whether a latecomer’s patent has higher proportion of science-based citation during catch-up process tend to depends on the nature of sector’s knowledge base.

The finding number four is that whether a latecomer’s patent has higher proportion of science-based citation tend to depends on the nature of sector’s knowledge base. This shows that the knowledge base of IT sector depends on radical innovation and explicit knowledge, while the knowledge base of automobile manufacture sector depends on gradual innovation based on experience and experiment and depends on tacit knowledge.

Catch-up mechanism at the firm-level

We have looked into the phenomena that have occurred in the process of catch-up by conducting in-depth analyses with indicators such as patents through the four catch-up cases. We have also investigated the cause and meaning of the results of the practical analysis. Through the catch-up cases that we have investigated, we can arrange the catch-up mechanism into the following principles. The catch-up mechanism occurs similarly or differently in the catch-up process for successful latecomer firms that overtook the leaders. For convenience sake, we attached a number to each principle. However, each number occurs simultaneously and in sequence.

First, latecomer firms trying to catch up with the leaders will seek to determine the direction of catch-up.

All catch-up cases of successful latecomer firms in this paper show that technological catch-up precedes the catch-up in the market. Then, why did latecomer firms try a technological catch-up which involves a lot of opportunity cost? Because, other followers can relatively easily imitate the catch-up process based on low-cost labor or marketing strategy. Also, fast followers start to realize the fact that technological catch-up is indispensable for sustainable dominance in the market. This awareness is an important factor in determining the direction of the catch-up process.

Second, successful latecomer firms imitate and learn from the leaders through the acquisition of external knowledge.

Huawei developed its own unique technologies after acquiring the technologies from Cisco and IBM[64].

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[64] Wang Y (2011). Langxingguanlizai Huawei (Wolf Management at Huawei), Wuhan: Wuhan daxuechubanshe (in Chinese)

Samsung also learned from Sony in its early stage, and likewise, Hyundai from Mitsubishi, and POSCO from Nippon Steel.

Third, the successful latecomer firms take advantage of specific strategies in their catch-up process.

The technological strategies show different aspects from sector to sector and from industry to industry in the real catch-up process. Latecomer firms in the IT sector try to catch up with the leader with up-to-date technologies when generation change occurs or when it is expected to occur. In this situation, we wonder if the leaders can prepare for the catch-up by developing new technologies. However, the leaders have difficulty in deciding whether to invest in new technologies, which have not proved valid in the market. The leaders are caught up in an incumbent trap for two reasons. First, they tend to underestimate the potential of new technologies because they have low profitability. Second, the increase in sales revenue through the investment in new technologies leads to the decrease of sales value through existing technologies, which is called Cannibalization. The latecomer firms that are trying to catch up with the leaders know that it is impossible to catch up with the leaders with the previous technologies with low added value. The investment in and development of new technologies are inevitable for the catch-up in the sectors with frequent generation change.

Then, what aspects will the latecomer firms, which belong to the regime with less frequent generation change, show in the catch-up process? The catch-up process through accumulated technological capacities applies to the regime with less frequent generation change as well. The failure cases of Daewoo and Proton in the automobile industry demonstrate that it is impossible to catch up with the leaders in the automobile industry without the technological capacities even though it belongs to the non-IT sector. The failure case of Bethlehem Steel, which tried to maintain its portfolio composed of low-profit products without any effort to improve technological capacities, shows the principle of catch-up through accumulated technological capacities[65].

The aspects for the latecomer firms show that the specific catch-up process is different from catch-up process in the IT sector. The latecomers have caught up with the leaders by improving existing technologies in a different way rather than implementing new technologies. The reasons are as follows. First, the benefits through the improvement of old technologies are greater than the benefits through the development of new technologies. This is in contrast with the IT sector. Second, "there is little difference between the technologies of last year and those of the previous year." This concept is different from the IT sector, in which new technologies always come up with new products within a few months. Even within the same non-IT sector, the aspect of catch-up is different between the automobile manufacturers, which tried to innovate products, and manufacturing processes, and steel makers, which tried to catch up through the innovation of equipment and facilities. We must remember that there is something different in the latecomer firm that has succeeded in accomplishing the catch-up.

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65 POSRI(2004), the survival strategy of steel makers in advanced countries in times of low growth

Chapter Six
Summary and strategic implications

Until now, we have made in-depth analyses of the patent data of the eight companies in the four catch-up cases and arranged the phenomena, which occurred in those processes, into four findings by answering the four research questions. We also investigated the reasons for such results through patent data and the meanings of the patent data. Chapter six discusses the strategic implications of the four findings with summaries.

Finding number one in this case study suggests that the latecomers' technological catch-up tends to precede the catch-up in the market. Thus, technological capacity is an important component in the process of catch-up in the market. We have observed that latecomers sometimes have a difficult time overtaking the leaders by using growth strategy based on low-cost labor, and comparative advantage without technological capacities.

This concept provides a lot of strategic implications to the companies in both developing countries and developed countries. The latecomers should realize the difficulty to overtake the leaders without the accumulated technological capacities. The leaders should adopt constant development approaches and the accumulation of technologies as a major strategy to maintain their dominance without being caught in the incumbent trap. The cases of Daewoo and Proton show that it is difficult to maintain dominance just by an economy of scale based on low-cost production or the acquisition of technologies without internalization through M&A strategies.

All of the successful latecomers, Huawei, Samsung, Hyundai, and POSCO in the four cases have accumulated their technological capacities by investing a huge amount of money in R&D five to ten years before their catch-up in sales revenue. These latecomers maintained their own in-house R&D centers. This demonstrates that a catch-up without technological capabilities is almost impossible and that there are strong implications about how to develop technological strategies for both latecomers and leaders.

The second finding suggests that the latecomer's qualitative technological catch-up with incumbents is seen in the sectors with frequent generation change. The most important factor to decide the technological nature of each sector is the frequency of technological generation change. In the ICT sector, the direction of technological development in the future is difficult to predict, which is due to the frequent generation change in technology. However, the generation change gives new opportunities to latecomers' catch-up by opening new markets and windows of opportunity. The sole opening of windows of opportunity does not ensure the success of every latecomer. Thus, latecomers that commit to a constant prediction of and preparation for the generation change can succeed in their catch-up.

The ten year trend in the quality of patents reveals that Huawei has predicted the generation change of technology and accumulated technological capacities for the generation change. Huawei did not reduce the investment in technology from the beginning and in the early 2000s when the IT bubble collapsed. The transition period from voicecentric 2G (generation) to date-centric 3G in the early 2000s came to Huawei as a window of opportunity. Samsung also succeeded in the catch-up by establishing a foothold in the period of generation change from analog to digital technology. Samsung's catch-up with Sony was such a dramatic event that no one had expected.

In this regard, the second finding gives important implications to both the latecomers and the incumbent leaders. Constant research and study of the future generation change of technology makes it possible for the latecomers to gain a foothold in the catch-up and for the leaders to maintain dominance. Both leaders and latecomers should pay constant attention to the direction of standard technologies and develop a strategy towards standard technologies. They also need to establish a strategy to review the potentials of the technologies, which are different from existing technologies. The second finding also implies that each company should develop a different technological catch-up strategy according to the sector that they belong to.

The implications of the third and fourth findings are as follows. The decision about whether to invest in up-to-date technologies for the catch-up of the latecomers should be different according to the sector. Although the process to invest in, file patents for, and acquire related technologies entails a lot of costs to the latecomer firms, the investment in new technologies are inevitable for them to make the upcoming generation change of technology as a window of opportunity. When a generation change of technology occurs, it is difficult to overtake the leaders in the area of existing technologies. However, this situation sometimes gives the latecomers chance to become a new leader in the new market with up-to-date technologies.

We expect this paper will provide strategic implications for the latecomer firms to catch up with the incumbent leaders in the future and for existing leaders to maintain dominance in the market.

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국문초록

기술과 시장에서 추격의 패턴
-4 가지 사례를 통한 특허 데이터 분석-

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본 연구는 초기 불리한 여건을 가진 개발도상국의 후발 기업이 거의 모든 면에서 우위에 있는 선진국의 선발기업을 어떻게 따라 잡을 수 있었는가라는 의문에서 시작해, 후발국의 추격 과정에서 발생할 수 있는 추격패턴이 존재하는가에 대한 논의를 한다. 이제까지 기업수준의 추격과정에서 어떤 일이 발생 했는가에 관한 몇몇 연구 있었지만 부분적인 설명에 그쳐왔다. 본 연구는 기존논문을 토대로 기업 수준에서의 추격 과정에서 어떤 일이 발생했는가 라는 질문을 구체화 하여 다음 네 가지의 구체적인 질문을 도출하였다.

첫 번째로 후발기업은 기술적 역량이 없이도 선발기업을 시장에서 추격이 가능한가 이다. 두 번째는 후발기업이 선발기업을 기술적 역량을 기반으로 추격을 했다면, 선발기업과 같은 기술을 기반으로 추격을 했는지 혹은 다른 기술을 기반으로 추격을 했는지, 세 번째로는 후발기업이 선발기업을 최신기술에 기반해서 추격을 하고 있는지, 마지막으로 추격의 과정에서 후발기업의 과학기반의 기술이 증가하고 있는지에 대한 의문이다. 위의 구체적인 질문에 답변을 위해, 본 연구는 기존의 추격이론을 충분히 검토하면서, 최근 활발하게 사용되고 있는 특허 데이터를 이용하여 기업 수준에서의 추격현상에 대한 심도 깊은

분석을 진행했다. 우선 이를 위해 우선 후발기업의 선발기업 추격과정에서 공통적인 패턴이 존재할 수 있는가를 염두에 두고 주요 섹터에서 선진국의 선발기업들을 개도국의 후발기업이 추격 했던 사례를 선별해 특허 분석 및 기술적 지표를 비교하였다. 본 연구는 추격의 사례로 통신장비산업에서 화웨이와 에릭슨, 전자산업에서 삼성과 소니, 자동차산업에서 현대자동차와 미쓰비시 자동차, 철강산업에서 포스코와 신 일본제철을 선택했고, 화웨이, 삼성, 현대자동차, 포스코는 모두 개도국 기반의 기업들로 각각의 섹터에서 이미 추격을 이루어낸 현재까지의 유일한 케이스이다. 위의 네 가지의 구체적 질문의 해답을 위해 기존문헌의 검토와 선정된 네 가지 성공적 추격의 사례를 통해 특허와 기술적 지표를 심도 있게 분석하는 과정을 거쳤고, 우리는 이를 통하여 질문에 대한 답변과 함께 후발기업의 추격과정에서의 아래와 같은 공통적인 패턴을 발견하는 성과를 얻었다.

첫째, 후발기업의 기술적 추격은 시장에서의 추격보다 선행하는 경향이 있다는 것이다. 이것은 축적된 기술능력이 추격과정에서 토대이며 지속 가능한 추격의 필요조건이라는 것을 나타내준다.

둘째, 후발기업은 선발기업과는 다른 기술을 사용하여 추격하는 경향이 있다는 것이다. 본 연구에서는 이에 대한 입증을 위해 두 기업간의 기술적 상호의존도, 특허 자기인용비율, 특허 피 인용횟수(질적 측면의 기술추격)등을 종합적으로 고려하였다.

셋째, 후발기업이 선발기업을 최신기술에 의존하여 추격하는가 여부는 해당 섹터의 기술적 특성, 특히 기술주기의 장단에 달려있다는 것이다. 이것은 기술주기가 짧고 기술적 세대교체가 빈번한 섹터의 후발기업은 선발기업을 최신의 기술로 추격을 하는 경향이 있는 반면, 그 반대의 섹터에 속한 후발기업은 최신기술에 대한 투자보다는 기존기술을 선발 기업과는 다른 방식으로 개선하는 방식으로 추격을 하고 있다는 것을 나타내준다. 본 연구에서는 이에 대한 입증을 위해 후방인용시차를 사용하였다.

넷째, 후발기업의 특허가 기초과학 비중이 높고 낮은 여부는 해당

섹터의 지식기반의 특성에 의존하는 경향이 있다는 것이다. 이는 IT 섹터에서는 지식기반이 급진적 혁신과 명시적 지식에 의존하는 특성이 있는 반면 자동차 같은 섹터의 지식기반은 경험과 실험을 통한 점진적 혁신과 암묵적 지식에 의존한다는 것을 보여준다.

본 연구는 특허 데이터 등 기술적 분석을 통한 위의 네 가지의 발견을 통하여 기업간 추격과정에 대한 다음과 같은 결론을 도출하였다. 축적된 기술적 역량이 후발기업이 선발기업 추격의 기반이고, 후발기업은 후발기업과는 다른 기술을 기반으로 추격하며, 기술적 주기가 짧은 섹터의 후발기업은 선발기업을 빠른 기술을 이용하여 추격하고, 암묵적 지식의 비중이 낮은 섹터의 기업은 추격과정에서 기초과학기반의 기술이 증가한다는 것이다.

마지막으로, 본 논문은 기술적 관점에서 특허분석 데이터를 통해 섹터 내에서의 추격 패턴이 존재할 수 있다는 것을 보여줌으로써 후발기업이 선발기업을 어떤 조건에서 추격할 수 있는가에 대한 몇 가지 방향을 제시할 수 있을 것이다. 또한, 후발기업과 선발기업 모두에게 기술 전략, 특히 특허전략을 수립하는데 있어서 실질적이고 유용한 시사점을 제공 할 수 있을 것이다.

주요어: 추격의 패턴, 기술적 추격, 시장추격, 특허, 기술적 상호의존도, 자기인용비율, 특허피인용횟수, 후방인용시차, 과학기반, 지식기반, 섹터

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