DIVERSIFYING SOURCES OF KNOWLEDGE, INNOVATION CAPABILITY BUILDING, AND CATCH UP

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ABSTRACT

This dissertation consists of three essays examining the role of connectivity in the catch-up process of a nation primarily focusing on East Asian countries. Specifically, I investigate the sourcing of knowledge, especially tacit knowledge, on local innovation capability building and thus catch-up process of a nation. I argue that for any country, sourcing from the diverse pools of tacit knowledge available in different parts of the world is a crucial requirement in maintaining a robust innovation eco-system. This becomes much more important in the catch-up process of a less-developed or emerging economy that is attempting to build local innovation capability.

In the first chapter, I lay the theoretical groundwork for the dissertation by reviewing how existing studies have contributed to our understanding of the catch-up process of an economy. Then, in the second chapter, I explore how the openness of an economy underpins contrasting economic outcomes by comparing the economies of South Korea and Brazil.

The third chapter emphasizes that the connectivity to the global innovation system is equally important for a more advanced economy such as Japan. Lack of such connectivity could lead to systemic "lock-in" in the long term. This is done by investigating the national systems of innovation of Japan in four knowledge-intensive industries: automotive, electronics, robotics and pharmaceuticals. Using patent data, I demonstrate that compared to other advanced countries such as Germany and Denmark, the Japanese innovation system is quite closed. I speculate that closedness to global

innovation systems could be one of the reasons for Japan’s prolonged economic recession and the underperformance of its once world leading firms.

The fourth chapter proposes an alternative catch-up strategy by investigating the innovation catch-up processes in Korea and Taiwan. These two Asian economies achieved developed status in a remarkably short period of time. Surprisingly, I found that these two countries are not well-connected to the rest of the world when it comes to innovation networks. These two countries achieved innovation catch-up rapidly by focusing on specific technologies that inherently require less reliance on learning through co-inventor networks. These technologies are the so-called “short cycle” technologies, i.e., technologies where the time period between innovation and maturation is very short. Therefore, relatively advanced technologies can be obtained in an “off-the-shelf” manner through outright purchase, licensing, and other means that do not require in-house wholly-owned innovation systems.

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CHAPTER 1: INTRODUCTION

1.1. Dissertation Overview

The major objective of economic development is for poor economies to achieve parity in terms of standards of living with wealthy economies. The process whereby this occurs is called “catch-up” or “convergence”. However, successful catch up is not guaranteed as economic development is a very complicated process. Many developing economies lag the advanced market economies by a significant margin and fail to catch up. According to the statistics provided by world bank, only 13 countries have successfully caught up since the 1960s (e.g., Agénor, Canuto, & Jelenic, 2012; Jankowska, Nagengast, & Perea, 2012). It has been, thus, of great interest to scholars to understand the process behind the successful catch-up of an economy.

The reason why many economies have struggled to catch up is primarily due to the fact that innovation catch-up or technological catch-up is much harder to achieve than output catch-up. Catch up is a step wise process whereby output catch-up (which relates to the capability to imitate the manufacturing processes of advanced economies) precedes innovation or technological catch-up (which is related to innovation, i.e., the capability to create new knowledge) (Lall, 1992; Mathews, 2002; Awate, Larsen, & Mudambi, 2012; Lee, Song, & Kwak, 2015). Even though many economies have successfully achieved output catchup, few economies have been successful in innovation or technological catch-up. This is because it requires more diverse sets of knowledge and involves a much more complex process than output catch up (Awate et al., 2012). True catch-up essentially requires innovation catch-up which will increase the chance of sustainable economic progress of an economy (Abramovitz, 1986; Verpagen, 1991; Kim, 1997; Bell & Pavitt, 1997; Giuliani, Pietrobelli, & Rabellotti, 2005; Fu, Pietrobelli, & Soete, 2011).

Firms are the main engines of the economic development of an economy (Porter, 1990), and a substantial volume of literature on Global Value Chains (GVCs) has pointed out connectivity of local firms to the global innovation system as one of the important factors for local firm's upgrading. This is because it enables technologically and managerially backward local firms to access new knowledge. Global linkages (mostly to advanced economies) provide opportunities for local firms in less developed economies to source advanced knowledge and increase learning through the interaction with MNEs from advanced economies. Although global linkages with MNEs from advanced economies in the form of buyer – supplier relationships has been acknowledged as an effective conduit for local firms to upgrade, studies have found that this is primarily limited to output catch-up as it hinders sophisticated tacit knowledge trasnfer (Schmitz & Knorringa, 2000; Humphrey & Schmitz, 2002; Giuliani, Pietrobelli, & Rabellotti, 2005; Navas-Aleman, 2011; Lee, Song, & Kwak, 2015; Szapiro, Vargas, Brito, & Cassiolato, 2016).

Unlike the interaction with MNEs, co-inventor networks have been shown to be effective for tacit knowledge transfer (Fleming & Marx, 2006; Breschi & Lissoni, 2009), thus local firm's innovation catch-up. The tacit nature of knowledge makes it difficult to transfer knowledge over long distances and therefore the knowledge becomes sticky within the geographic boundaries. The transfer of such knowledge, hence, requires not only close interaction between the giver and the recipient of the knowledge (Von Hippel, 1994), but also comprehensive understanding of the cultural and institutional context in which it was created (Maskell & Malmberg, 1999; Gertler, 2005). As an informal knowledge conduit by nature, co-inventor networks help firms to overcome such difficulties and allows firms to tap into different, new knowledge residing in other countries as co-inventors develop comprehensive understandings and trust with each other by working on a project for an extensive period of time and also alleviate the problem of distance by meeting each other through temporary co-location events such as trade fairs and conferences. This, therefore, becomes a much more apt vehicle for an economy, be it advanced or less advanced, to develop local innovation capability.

Acknowledging connectivity becomes much more important as an economy makes progress, this dissertation explores the role of connectivity, more specifically connectivity through co-inventor networks, in the economic development process specially focusing on East Asian countries.

The first chapter explores how the openness of an economy which is the prerequisite of connectivity makes divergent economic outcomes by comparing two economies of South Korea and Brazil. Through the early 1980s, Korea had lower per capita income than Brazil. However, in the ensuing decade and a half, the Korean economy grew rapidly and by 1996, the country was admitted to the OECD. In contrast, Brazil failed to make significant progress, becoming stuck in the so-called “middle-income trap”. The economic development process is enormously complex, but through a comparative analysis, I identified the key difference between these two economies-i.e., outward orientation, which affected the ways in which local firms compete, interact, and learn. Under this overarching umbrella of engagement with the global economy, I further identified three key factors underpinning Korea's successful catch-up: 1) well planned and consistent government policy; 2) technological specialization; and 3) the nurturing of corporate champions.

The second chapter emphasizes that connectivity through the linkages to the global innovation system is equally important for a more advanced economy such as Japan. Japan presents us with a very intesrting question as it shows a bimodal performance: Japan is one of the biggest economies in the world and third largest R&D investor. However, its economy has suffered from more than two decades of economic stagnation, and many of its formerly world-class firms have lost their competitiveness in global markets. This has been a puzzle.

Scholars have proposed many factors behind this interesting phenomenan, but in this paper I suggest that lack of connectivity, especially connecitivty through co-inventor networks, or inward looking innovation system of Japan could be one of the important reasons for its prolonged economic recession and underperformance of its once world leader firms. Analysis shows that Germany, a similar scale economy to Japan, shows a much higher level of connectivity to the global innovation system than Japan. This "unsusally" closed innovation system could pose a serious danger to Japan in the long run as it could lead to a systemic lock in problem.

The third chapter proposes an alternative innovation catch-up strategy by investigating the innovation catch-up process in Korea and Taiwan, the two Asian economies that achieved remarkable economic development in a short period of time. Even though connectivity through co-inventor networks has been emphasized as one of the key mechanisms to develop innovation capability in the literature, the extent to which it has played a role in the economic development process of these two economies is different.

These two Asian tigers have achieved successful innovation catch-up while remaining relatively disconnected from global co-inventor networks. Instead of relying on co-inventor networks, local firms in these economies have achieved innovation catch-up by focusing on those emerging technologies that exhibit inherently short cycle times. Focusing on technologies with short cycle times indicates that there is a less need for local firms to rely on learning knowledge through co-inventor networks, thus allowing local firms to cut through the lengthy learning process and realize a quick commercialization success.

Further, the results also show that the different nature of business groups in these countries partly explains their different degrees of connectivity to the global innovation system. Due to differences in government policies, Korean business groups and Taiwanese business groups show a stark difference in size and degree of diversification. By being big and extensively diversified, Korean business groups relied more on internal networks than their counterparts who are smaller and less diversified.

In summary, this dissertation has examined the role of connectivity on innovation outocmes specifically related to catch-up processes. While connectivity to the global innovation system has been documented in many catch-up experiences (Chinese manufacturing, Indian IT) (Fu, Pietrobelli, & Soete, 2011; Lorenzen & Mudambi, 2013), I document a lack of such connectivity in many East Asian economies. While there appears to be alternative catch-up paths where connectivity is less important, once an economy achieves advanced status, continued innovative isolation is fraught with danger.

CHAPTER 2: ESCAPING THE “MIDDLE INCOME TRAP”: THE DIVERGENT EXPERIENCES OF THE REPUBLIC OF SOUTH KOREA AND BRAZIL

2.1. Introduction

Countries with similar starting points may see vastly different economic growth patterns, owing to different cultures, economic policies, institutions or asset endowments (Azariadis & Drazen, 1990). Some of these differences can have paradoxical effects like the so-called “resource curse” (Auty, 1993: 1). For example, it has been observed that natural resource-rich developing economies have generally performed worse than less well-endowed countries in the decades following the end of World War II (Auty, 1993). South Korea (hereafter referred to as Korea) and Brazil illustrate this case.

Up until the early 1980s, Brazil posted a strong economic growth rate, underpinned by a diversified manufacturing sector and solid export performance (Moreira, 1995). Throughout the decade, it had reached a per capita income level of US$3,000, a level considerably above that in other emerging markets of the time, such as Korea and Taiwan (Aiyar, Duval, Puy, Wu, & Zhang, 2013). Yet, the Brazilian growth rate then fell sharply, hampered by sharp declines in output and manufacturing exports. The country has since failed to break through to higher income levels, lagging the growth of many other emerging economies. By 2013, Brazil's GDP per capita ranked 95th in the world (Elstrodt, Manyika, Remes, Ellen, & Martins, 2014).

As seen in Figure 1, Korean GDP per capita at the onset of industrialization in 1961 was $91.48, compared to $203.19 for Brazil and the latter country maintained a higher level until 1983. However, despite this later start in economic development along with lack of natural resources, Korea progressed rapidly, surpassing Brazil's per capita income in the mid-1980s and eventually evolving to an "rich" economy by 1996 (Felipe, Abdon, & Kumar, 2012). Indeed, Korea is considered one of the best-known examples of a developing economy that successfullly achieved the living standards of the developed world, one of only 13 countries that were able to make this transition since the 1960s (Agénor, Canuto, & Jelenic, 2012).

In this paper, we study a particular instance of this contrast, undertaking a comparative analysis of the economies of Korea and Brazil. Throuth a comparative analysis of these two contrasting economies, we draw some general lessons for successful economic development policy. A large volume of literature points out a wide range of contributing factors to successful catch-up, but few studies offer a comprehensive view. The focus of much of the extant literature has primarily been on the role of the government in economic development (e.g., Bell & Pavitt, 1993; Gerschenkron, 1962; Lall, 1992; Mahmood & Ruffin, 2005). As the catch-up processs is complicated, it is extermly hard to tease out one contributing factor for the successful catch-up. Our comparative analysis of the Korean and Brazilian economies, however, seems to reveal that the most fundamental element underpinning successful economic development is maintaining an outward-oriented or open economy. This is the overarching long-term difference between two countries (Moreira, 1995). Although the concept of outward-orientation/openness is broad and vague, most economists confine it to include international trade in goods, i.e., the extent to which a country engages in global trade through exports (Harrison, 1996; Weinhold & Rauch, 1997; Yanikkaya, 2003). Statistics have shown that Korea’s export as a percentage of GDP has been consistently higher than that of Brazil, rising to 52.6% of GDP by 2010 (see Figure 2), reflecting a greater outward orientation/openness in Korea and a lesser outward orientation/openness in Brazil.

Under the overarching umbrella of engagement with the global economy, we identify three specific main factors behind Korea's successful economic development: 1) a well-planned and consistent government policy, 2) a narrow technological focus, i.e., the technological specialization of a national production and innovation system, and 3) the encouragement of selected large local firms that demonstrate the wherewithal to compete and succeed in global markets. It is difficult to identify the separate contributions or causal relationships amongst these three factors. However, economic development of an economy that is rapid enough to result in successful catch-up can be considered as the interplay of all these three factors.

2.2. Theoretical foundations of catch-up in emerging markets

It has been widely acknowledged that a nation's technological capability is a determinant for the different national economic performance and growth across countries (Freeman, Clark, & Soete, 1982; Bell & Pavitt, 1997; Castellacci, 2008). The literature on economic catch-up emphasized the importance of narrowing the technological gap between developing countries and developed countires (Abramovitz, 1986; Kim, 1997). The key idea behind the catch-up process is that the greater the technological gap existing between a developed country and a developing country, the more potential there is for a developing country to grow rapidly (Abramovitz, 1986) as the marginal effects of the technologies on economic growth are much greater for emerging economies than for advanced economies (Hannigan, Lee, & Mudambi, 2013). The current evidence on the actual process of catch-up across different emerging market countries seems to agree on the importance of acquiring technologies from advanced economies through relationships with advanced economy firms (e.g., Kumaraswamy, Mudambi, Saranga, & Tripathy, 2012) along with developing capabilities in-house through learning-by-doing (e.g., Park & Lee, 2006). As Abramovitz (1986) emphasized, local firms in developing economies must balance these two.

In local firms' upgrading process, a substantial volume of the global value chain (GVC) literature notes that foreign MNEs are the main knowledge transmitter (Ivarsson & Alvstam, 2005; Kogut & Zander, 1993; Patibandla & Petersen, 2002). Giuliani, Pietrobelli, and Rabellotti (2005), for instance, investigate the upgrading process of domestic firms in Latin America by clustering in industrial districts. Those firms are able to overcome growth constraints through a sequential upgrading process–i.e., process upgrading, product upgrading, functional upgrading, and intersectoral upgrading, thereby contributing to global value chains (GVCs). Firms in emerging economies are able to go beyond production capability or imitation capability, the skillls involved in optimizing the operation of established plants (Amsden, 1989), and eventually achieve innovation capability, the skillls and technologies necessary to differentiate products or services (Awate, Larsen, & Mudambi, 2012).

To understand and implement sophisticated technologies invented abroad, however, requires that more skills must be build up by domestic workers and managers – i.e., absorptive capacity of the economy (Keller, 1996). Technologies are tacit in nature, and their underlying principles are not always clearly understood (Lall, 1992). Therefore, learning is essentially required for technology transfer. Dahlman, Ross-Larson, and Westphal (1987) show that the probability of a successful technological transfer is highly dependent on whether or not the workers study, train and practice well in advance of the inception of the new project. In a similar vein, Amsden (1989) argues that Hyundai, a South Korean multinational conglomerate, could never quite replicate the shipbuilding process until it began to learn some of the underlying technologies.

Indeed, a substantial amount of literature on newly industrializing countries (NICs) investigate the differences among such countries as to their relative emphasis on human capital as well as technology investment (e.g., Amsden, 1989; Keller, 1996; Moreira, 1995). A relatively high initial level of human capital should be beneficial in the acquisition of new technologies, and if a country moves towards an outward-oriented regime which gives access to new technologies at a higher rate, then a correspondingly higher rate of human capital will be necessary to sustain the process of technological development and higher overall growth. The general hypothesis in this literature is that absorptive capacity is critical for domestic firms' catch-up in emerging markets. In other words, absorptive capacity at a national level as a whole lays a foundation for the evolution of absorptive capacity at a firm level such that the capacity of firms to create new products or services also increases over time. In virtue of the outward-oriented government policy which puts greater emphasis on a strong commitment to education as well as science and technology (S&T), domestic firms in newly industrializing countries to access to advance economy firms' state-of-art technologies and secure qualified knowledge workers (Amsden, 1989).

2.3. Key factors behind the successful catch-up of Korea

2.3.1. Government Policy

Government policy plays a crucial role on the catch-up process: the different orientation of government intervention and the extent of government intervention ultimately determine international competitiveness (Porter, 1990). Especially in the case of developing economies, its role becomes much more influential. The literature has highlighted the role of government in enhancing technological capability at the national level by placing a heavy emphasis on human capital, technology investment and infrastructure (e.g., Amsden, 1989; Keller, 1996; Moreira, 1995). Rapid growth requires sophisticated planning capability and the involvement of patient investment capital. Building on the early work of Gerschenkron (1962), developmental-state theories provide a model of a nation's economic development that emphasizes the active role of the state in creating an export-based industrial system and facilitating the technology transfer to support it (Breznitz, 2007).

Korea and Brazil show a stark difference in terms of the orientation of government intervention and the extent of government intervention, which had resulted in different patterns of education and training of the labor force, technology acquisition, commitment of resources to technological learning (Viotti, 2002), thereby leading to different paths of catching-up and resultant chance for successful catch-up.

In the case of Korea, government intervention was guided and disciplined by the aim of international competitiveness. Specifically, tying superior export performance to success has long been a part of industrial policy in Korea. Indeed, as early as 1965, Korea's President Park had already begun to talk about global competitiveness, emphasizing that competing with others in the international export race is not a choice, but a compulsion (Amsden, 1989). From its earliest days of export-led development in the mid-1960s, government policy was aimed at creating internationally competitive capabilities in the domestic economy. This export-led growth strategy was executed at two levels – strategic and tactical. At the strategic level, the government identified appropriate industries using sophisticated product cycle logic (Vernon, 1966). At the tactical level, it devised and implemented a comprehensive system that linked import-control with various means to promote exports such as export credit, taxation benefits, and duty drawback (Mah, 2007). It is also important to recognize that Korea commenced heavy investments in its physical infrastructure and educational system which is essential for industrial development right after the end of the Korean War in the early 1950s. It set education as a strategic priority and facilitated access to secondary and tertiary education, creating a large pool of skilled workers and engineers, thus laying the foundation for Korean firms to build and upgrade their competencies by conducting internal R&D essential for innovation. In addition, large government-funded institutes were set up to carry out applied R&D and engineering and to train engineers and researchers (Hobday, 1995).

In contrast, the inward-oriented Brazilian government adopted an import-substitution policy, incentivizing domestic firms to serve the local market through the mid-1990s (Alcorta & Peres, 1998; Figueiredo, 2008). Its policy had a second objective, namely the avoidance of a balance of payments crisis (Moreira, 1995) rather than technological development (Alcorta & Peres, 1998). Its industrialization which did take place was always a by-product of external crises which limited the supply of imports (Baer & Kerstenetzky, 1964). Even though some technology transfer regulations exist which is designed to ensure a degree of local diffusion, most of them were difficult to put into practice (Alcorta & Peres, 1998). Exporting in Brazil was associated with backwardness due to centuries of colonial history when raw material exports served foreign interests (Moreira, 1995). As a consequence, the Brazilian government focused on protecting domestic industry rather than exposing them to competition in the global market. In addition, the Brazilian government's investment in the hard infrastructure as well as education and skills has continued to be inadequate to support significant indigenous technological efforts. Brazil has invested on average just 2% of GDP on hard infrastructure during the period of 1980 to 2006. This is far below the investments made by fast-growing Asian countries which averaged 7% of GDP (Carranza, Daude, & Melguizo, 2014). In addition, South Korea and Brazil show a substantial disparity in the length of average schooling over the four decades (Jankowska, Nagengast, & Perea, 2012). This led to a relatively poorly qualified workforce and poor science and technology infrastructure (Moreira, 1995), that were further obstacles to increasing local firms' competitiveness to global levels. As of 2013, The World Economic Forum ranks Brazil 114th and 121th in the world for the quality of overall infrastructure and education respectively (Schwab, 2013).

There is also a stark difference in terms of the manner in which each government implemented its policy. The Korean government maintained a consistent policy regime over a period of five decades and its ultimate goal had always been increasing international competitiveness through indigenous technological efforts. In contrast, the Brazilian government did not pursue industrialization in a systematic manner with the great number of ad-hoc institutions (Alcorta & Peres, 1998). Brazil’s industrialization was more the result of external shocks rather than government strategic planning.

2.3.2. National Technological Focus

The limited availability of resources in developing economies makes it crucial that these are concentrated in the sectors and associated technologies where the country has the largest comparative advantages. The government can identify the more promising sectors for engagement with the global economy and shift strategic resources towards them (Mancusi, 2001). In essence, technological specialization at the national level allows an economy to build a high level of absorptive capacity in the selected industries and develop the capabilities to further compete in global markets. The Korean government was keenly involved in shaping the industrial structure towards more efficient configurations and remedying weak financial systems and education systems (Amsden, 1989). Its industrial policies were outward focused and followed the dictates of Ricardian comparative advantage, updated with a keen appreciation for the product cycle model. This was the antithesis of the central planning approach which was focused on fulfilling domestic needs with domestic production. With the aim of building an internationally competitive industry, Korean policy charted a path of industrial transformation from labor-intensive industries to heavy and chemical industries (HCIs). For instance, to achieve the successful industrial shift, the Korean government came up with the series of Five-Year Plans or the "Big Push" which set specific investment and export targets for each of the selected industries within the Heavy and Chemical Industrialization (HCI) policy (Galbraith & Kim, 1998; Moreira, 1995).

The Brazilian government's policy efforts, on the other hand, significantly differed from the Korean approach along two important dimensions. First, it bore greater resemblance to communist and socialist inward-facing central planning and was aimed at import-substitution rather than export promotion. Second, it lacked consistency and continuity such that its emphases tended to vary from government to government. The so-called 'Targets Plan' aimed at developing heavy industry was neither specified in detail nor accompanied by significant institutional changes (Moreira, 1995). It was little more than a collection of five-year targets for output and investment in heavy industry, without a specification of how these targets were to be achieved. Further, the functional intervention to fundamentals to support the development of heavy industry such as transport, energy, and education system was very limited (Moreira, 1995). Investment in education and training, which is critical for the technological development, has been lower than the world average, albeit the highest among Latin American countries (Alcorta & Peres, 1998).

As seen in Figure 3, a very high percentage of Korean firms' innovative activities are concentrated in a limited set of industries such as electrical and electronics and computers and telecommunications where Korean firms have established world-leading market shares (Mundy, 2013). By contrast, Brazil has not established a world leading market share in any industry. Its innovative output is rather dispersed across a wide range of industries and is even negligible in every one of them, which inherently prevented firms from concentrating their limited technological resources in a smaller set of key products that could have been competitive in international markets (Frischtak, 1990).

2.3.3. Corporate Champions

The agent of economic expansion in all late-industrializing countries was what Chandler (1977) described as the large-scale multidivisional enterprise due to the institutional voids. In many countries, these large firms laid out the basis for sustainable economic growth (Amsden, 1989). Indeed, economic development of Korea was heavily based on the efforts of large diversified business groups or known as *chaebols.* The emergence of large conglomerates during the industrialization was an efficient institutional response to the institutional voids and market failures that characterized an economy during its underdevelopment phase (Khanna & Palepu, 2000; Levy & Kuo, 1991). Large firms can overcome the handicaps of underdeveloped economies by internalizing financial, labor and other resource flows. This enables them to enter new industries at minimum cost and at a rapid speed, enhancing their abilities to compete in global markets (Amsden, 1989). In addition to the size, there were also internal factors that led Korean firms to also develop world-class capabilities. Their mindset to become globally competitive firms also played a pivotal role. Since their domestic market is relatively small, South Korean companies had limited scope to expand domestically. Unlike Brazilian firms that could generate comfortable performance based solely on their large domestic market, Korean firms had to be outward-focused merely to survive in the face of domestic competition. Harsh export requirements forced Korean firms to reduce costs and keep quality high (Hobday, 1995). As a consequence, unlike Korea, we observe few corporate champions in the Brazilian economy (see Figure 4).

As noted previously, the Brazilian government devoted its efforts to protect domestic firms from foreign competition and was not outward-oriented in giving subsidies. Having a large domestic market, Brazilian firms, however, had less incentive to further upgrade themselves (Moreira, 1995). Having a large domestic market may have given them a sense of security. As a consequence, unlike South Korea, we observe few corporate champions in the Brazilian economy. In fact, big firms in Brazil were mostly state-owned companies in the nature resources sector and foreign-owned subsidiaries. Export growth was mainly the result of the global sourcing strategies of multinational enterprises from advanced economies such as U.S. and Europe (Gereffi & Wyman, 2014). Indeed Dahlman and Frischtak (1993) concluded that Brailizan firms are basing their market position on extensive exploitation of natural resources and reliance on low-wage labor and low-tech manufacturing than on productivity of labor and innovation. As seen in Figure 4, the top Brazilian assignee is Petrobras, a Brazilian semi-public energy corporation.

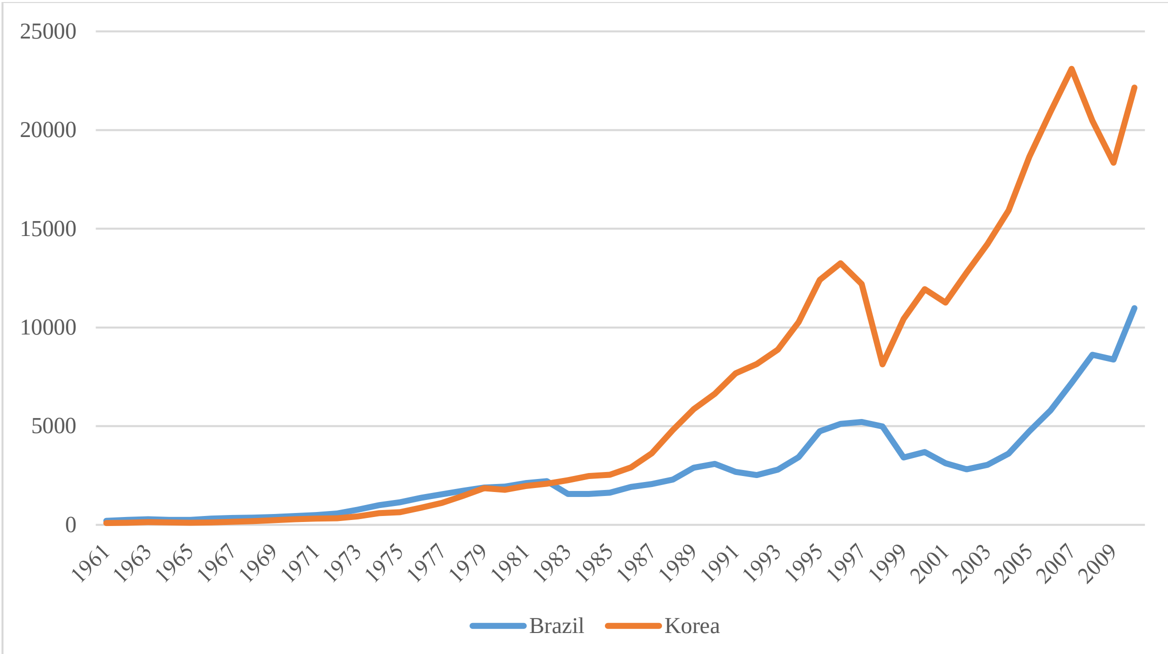
2.4. Korea and Brazil today and moving forward

Reflecting a divergent economic outcome, the level of innovation capacity is quite different between Korea and Brazil (see Figure 5). While patenting in both countries rose in the 1990s, Korea's growth far surpassed that of Brazil. Specifically, the number of patents assigned to Korean entities has risen sharply, with a cumulative total of 84,751 by 2010, whereas the corresponding figure for Brazil is only 3,034. Further, differences in innovative capacity between the two economies become even more severe if we compare patents per capita: Korea's patents per capita is 1,695.02, while the corresponding figure for Brazil is only 15.26. The 2007 global capabilities (GloCap) index comprised of various technological indicators such as knowledge and skills and infrastructure reveals that Brazil's technological capabilities (0.013) are much lower than Korea's (0.529) (Buckley & Hashai, 2014; Filippetti & Peyrache, 2011).

Although there are no simple solutions for other economies due to a different history, geography and set of economic opportunities and problems, to escape from the "middle-income trap" and evolve further into a more innovative economy, it may be necessary for Brazil to follow Korea's example by gaining a firmer foothold in the global value chains of major knowledge intensive industries (Mudambi, 2008). Many Korean firms progressed successfully from simple radio and TV assemblers for the global buyers in the 1960s to advanced producers of industrial electronics and components in the 1980s (Hobday, 1995). However, simple insertion into the global value chains of multinational enterprises from advanced economies may not be enough for local firms to upgrade themselves. Although extensive literature on Global Value Chains (GVCs) argues that the engagement of local firms into the global value chains of multinational enterprises could offer the possibility for local firms in developing economies to embark on a path of progressive upgrading (e.g., Gereffi, 1999), several studies found evidence that global buyers do not facilitate functional upgrading, moving into higher value added activities such as branding, marketing, and innovation, of local firms in developing economies as they fear that they will encroach their business directly (Giuliani, Pietrobelli, & Rabellotti, 2005; Humphrey & Schmitz. 2002; Lee, Song, & Kwak, 2015; Schmitz & Knorringa, 2000). Faced with such difficulties, therefore, many of local firms never upgraded themselves in a better position in strategic stages of the productive chain such as marketing, design, and branding activities which yields higher rents (Schmitz & Knorringa, 2000; Vargas & Alievi, 2002).

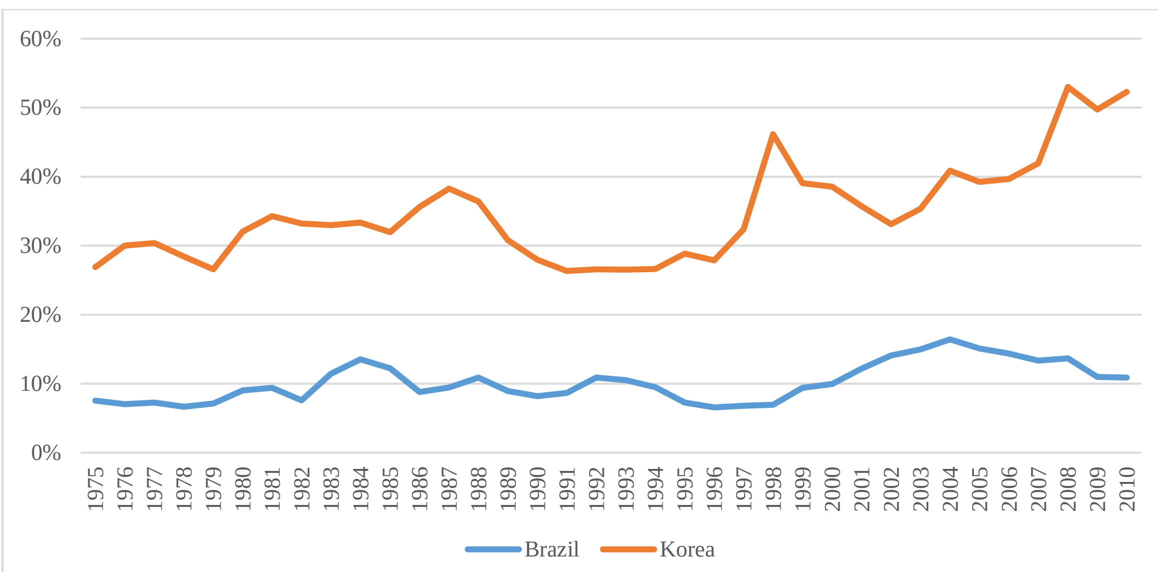
This would involve a serious change in policy: the government should be determined to increase the competitiveness of specific industries by giving incentives as well as sanctions conditional on firm performance. Brazilian firms became quite spoined by the opportunities in large domestic market for a long time, and without firms' aggressive attitude looking for opportunities outside of the domestic market, no macroeconomic policy would make local firms competitive. Identifying and investing in industries where Brazil has a comparative advantage and that are suited to Brazil's stage of development are also important. But, above all these, it is impossible to over-emphasize the importance of addressing fundamentals for sustainable growth by focusing on building a good science and technology infrastructure, as well as a strong education system to develop human capital.

Figure 2.1: GDP per capita (current US$)



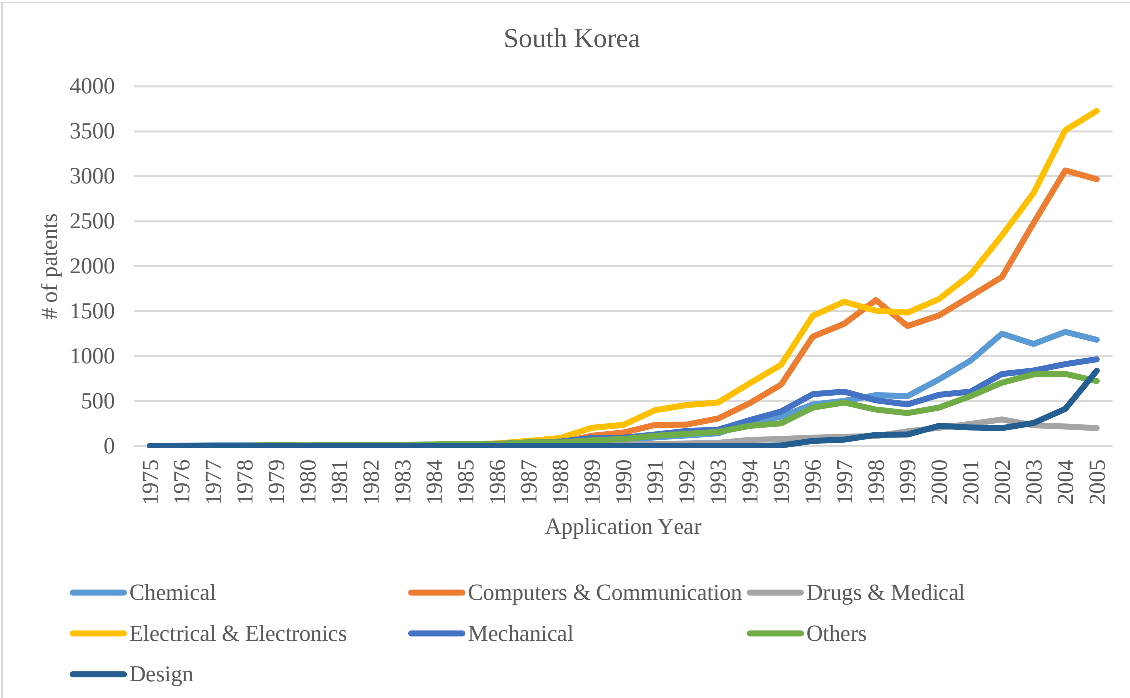
Source: World Bank

Figure 2.2: Exports of goods & service (% GDP)



Source: World Bank

Figure 2.3: Industrial focus



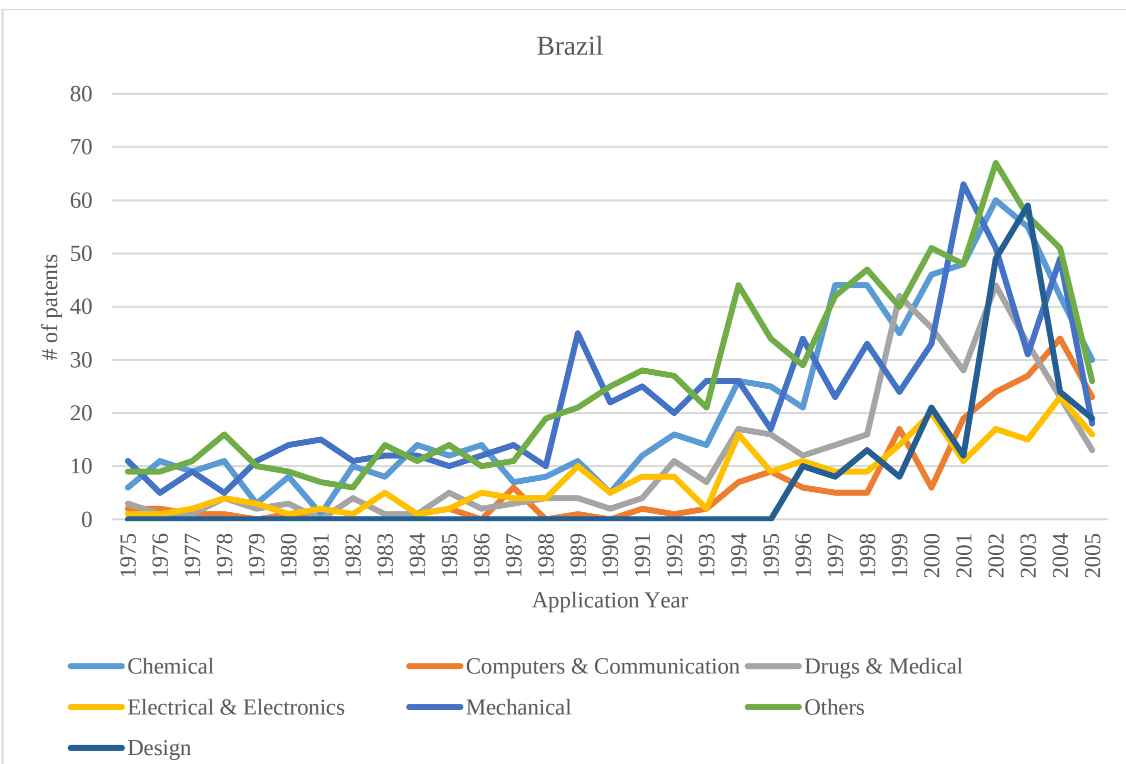
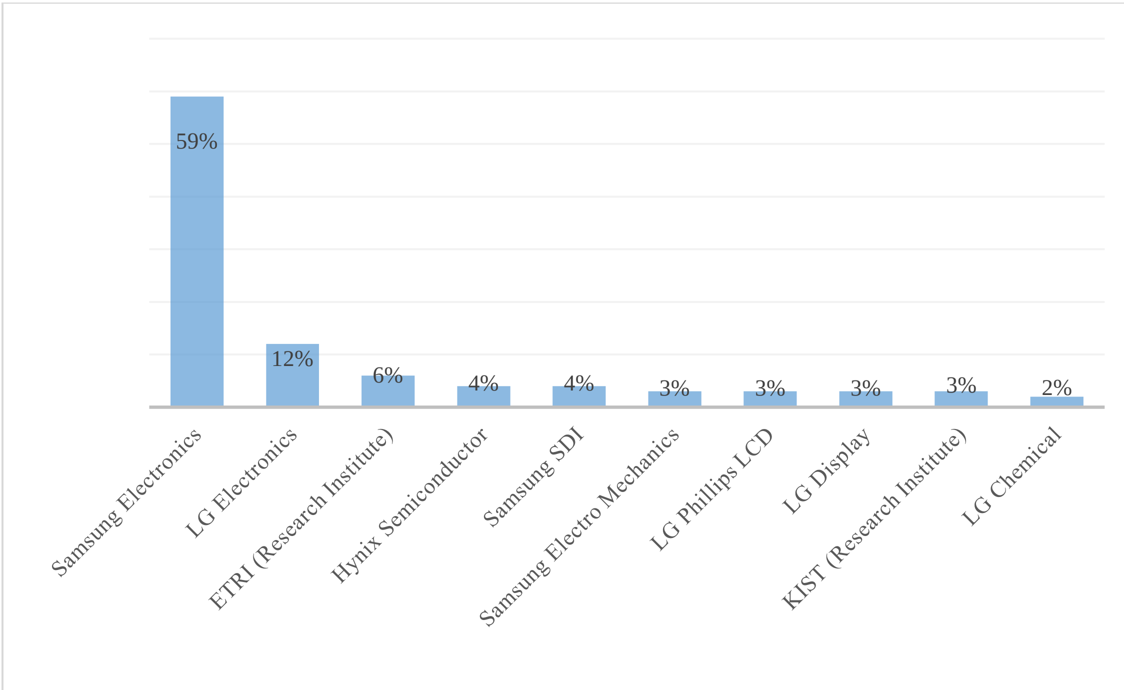


Figure 2.4: The composition of patent ownership: Top 10 assignees in South Korea and Brazil



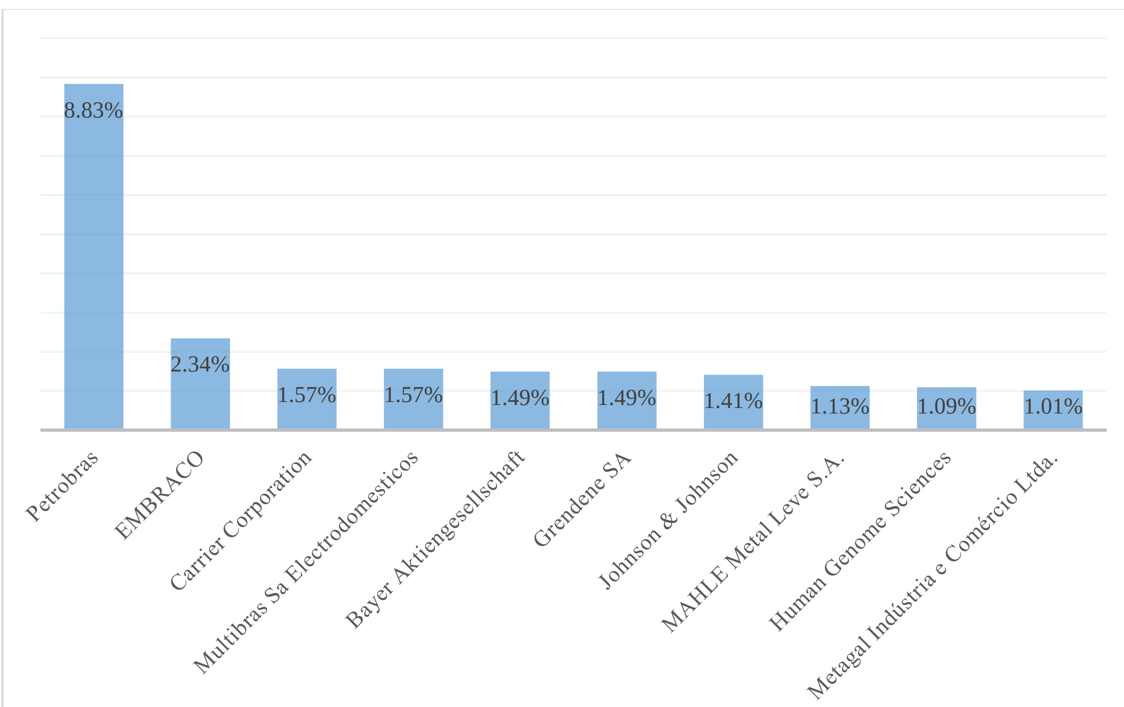
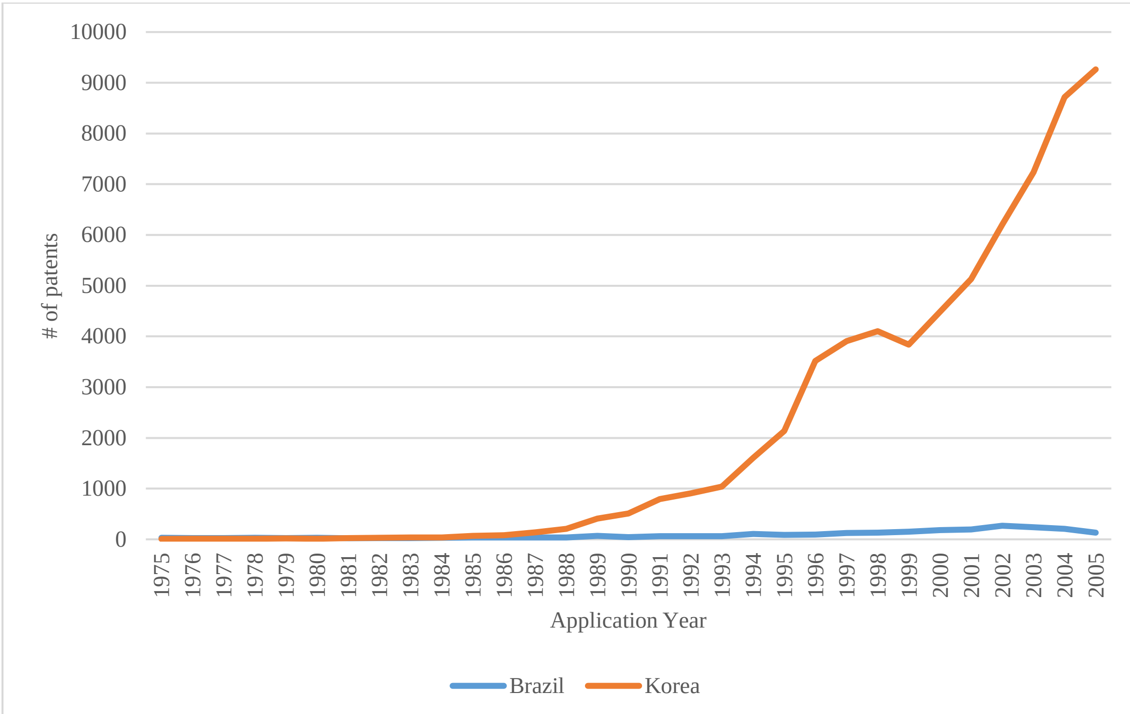


Figure 2.5: Number of USPTO Patents with Links to South Korea & Brazil, 1975-2005[1]



[1] Due to the truncation problem (Hall et al., 2001), interpretation the data after 2005 should be with care, and therefore, the data after 2005 was excluded.

CHAPTER 3: AN ANALYSIS OF JAPAN'S CONNECTIVITY TO THE GLOBAL INNOVATION SYSTEM

3.1. Introduction

A nation's competitiveness crucially depends on the ability of its constituent firms to innovate (Porter, 1990). Indeed, the capacity to improve its constituent firms' productivity through constant upgrading, differentiation, and innovation in all major sectors of a nation is critical to a nation's prosperity (Cantwell & Zhang, 2009; Hodgetts, 1993). The literature on economic development suggests the heterogeneous development paths observed across countries can be ascribed in large part to differences in national technological capabilities (Castellacci, 2008; Freeman, Clark, & Soete, 1982; Gerschenkron, 1962). The ability of its constituent firms to innovate has become much more critical in recent decades as the basis of competition has shifted toward the creation of knowledge (Mudambi, 2008).

Japan presents a puzzle that motivates an interesting research question. Why does Japan as a whole continue to produce a higher output of innovation than almost any other economy, but yet the Japanese economy performed poorly in recent decades? Furthermore, Japanese firms remain among the most prolific producers of patented knowledge in the world, but the country has lost competitiveness in several industries, in spite of remaining a world leader in terms of the production of innovation. Many reasons may explain to this bimodal performance of high innovation production but loss of competitiveness, and explaining them all would be beyond the scope of this paper. We decided instead to focus on one particular aspect that we consider a likely contributing factor: the scarce global connectivity of the Japanese national system of innovation to the global innovation system. While this is probably not the only problem Japan is facing, we argue that an inward-looking innovation system is a hindrance that exacerbates Japan's problems. Both the literature on national systems of innovation (NSI) (Lundvall, 1992; Nelson 1993) and the Triple Helix approach (Etzkowitz & Leydesdorff, 2000) have pointed to government policy, firm strategy and university linkages as the critical components of national innovation capabilities. However both these literatures are largely inward-focused; while international linkages are recognized, they are not highlighted. However, with an increasingly inter-connected and inter-dependent global innovation systems, "lock-in" becomes as a serious danger, especially for advanced economies (Narula, 2002). Actively sourcing new knowledge residing in other countries becomes much more salient given that in a world of global competition, even the most technologically advanced countries cannot be self-sufficient (Narula, 2003).

In order to improve their innovation performance and remain competitive, firms in a country need to complement local knowledge pools with advanced technological knowledge available in other countries (Cantwell & Mudambi, 2005, Giuliani, Martinelli, & Rabellotti, 2016). This enables them to constantly generate innovative products and thus be in a better position to compete in a global market (Bierly & Chakrabarti, 1996). There are several mechanisms, such as foreign direct investment (FDI) and licensing, which allow firms in a country to access foreign national innovation systems. FDI, in particular, can be used to transfer knowledge within firm boundaries in a more effective way than through market mechanisms (Buckley & Casson, 1976). The embeddedness of MNE subsidiaries within different countries allows firms to access knowledge from host locations (Ghoshal & Bartlett, 1988; Rugman & Verbeke, 2001), which in turn can be transferred back to headquarters (Gupta & Govindarajan, 2000; Håkanson & Nobel, 2001; Mudambi & Navarra, 2004; Yang, Mudambi, & Meyer, 2008). The dispersion of value chain activities, including innovation, is therefore one of the pillars of this knowledge sourcing process.

While our study focuses on patented knowledge, which requires a degree of codification, the networks necessary to conduct innovation activities across geographically dispersed locations also facilitate the transmission of the tacit components, particularly when these networks are dense and stable over time. The transfer of codifiable knowledge is relatively simple, but the transmission of tacit knowledge requires a higher degree of socialization or co-location between the contributors and receivers of knowledge. The existence of highly localized centers of excellence or pools of specialized knowledge in remote locations, often forces firms to disperse innovative activities that have a significant tacit component. This geographically dispersed creation of tacit knowledge, however, is really effective only in companies that have developed complex international networks for technological learning (Cantwell & Santangelo, 1999). One of the main mechanisms through which this dispersion of knowledge creation is operationalized is co-inventor connectivity. While the patents themselves are codified, the co-inventorship process is one of the mechanisms that allow tacit knowledge to be transferred (Agrawal, Cockburn, & McHale, 2006; Breschi & Lissoni, 2009; Fleming & Marx, 2006). Co-inventor networks reduce the difficulties of transmitting tacit knowledge over geographical distances, since co-inventors usually work together on a certain research project for an extensive period of time through which they develop common understandings and the bonds of trust which are essential for learning to take place (Breschi & Lissoni, 2009). Co-inventor teams are often made of different nationalities, creating diversity in terms of ideas and knowledge. Countries have been shown to vary in terms of where their technological strength lies (Cantwell, 1989) and these distinctive technological strengths can be transferred through co-invention networks. As a consequence, working on a research project with inventors from a different national context increases the chance of accessing new tacit knowledge residing in that global innovation system.

In this study, we analyze the NSI of Japan through its co-inventor network using patent data from the US Patent and Trademark Office (USPTO) over the period of 1975-2004. Our patent analysis shows that unlike other advanced countries such as Germany and Denmark, the Japanese innovation system is surprisingly closed in terms of co-inventor connectivity. This is quite counter-intuitive given that connectivity to the global innovation system is widely accepted as a mechanism to boost competitiveness. We suggest that being closed to global innovation system, particularly in terms of sourcing the most tacit capabilities (Cantwell & Santangelo, 1999) might be one of the reasons why the Japanese economy has witnessed poor performance in recent decades (Fukao, 2013). More specifically it may underlie the diminished competitiveness of many of Japan's formerly world-class MNEs.

Our contributions are twofold. First and foremost, we add to the literature that advocates the position that the domestic components of NSIs can only realize their potential if they are reinforced with international connectivity (Bathelt, Malmberg, & Maskell, 2004; Lorenzen & Mudambi, 2013; Narula, 2002). We argue that the importance of international connectivity has been steadily rising over the last few decades and is most important for the tacit aspects of knowledge (Hannigan, Cano-Kollmann & Mudambi, 2015). Our analysis of co-inventor connectivity addresses both of these important issues.

Second, we present Japan as an empirical example. The Japanese NSI represents an interesting case, as Japan is currently the world's third largest economy and the world's third largest R&D investor (Riemschneider, 2016). It has consistently maintained one of the highest R&D / GDP ratios in the world (Dutta, Lanvin, & Wunsch-Vincent, 2015). Yet it has witnessed significant losses in global competitiveness over the past few decades (Fukao, 2013; Fukuda & Yamada, 2011). Japanese firms once dominated the world markets for electrical and electronics products. However, in recent years, Japanese MNEs like Sony and Matsushita have faced stiff competition from rivals in the US (e.g., Apple), South Korea (e.g., Samsung) and even newer firms from emerging economies. In the process, they have lost their market share in both domestic and global markets (*The Economist*, 2014). Much of the literature on the Japanese economic malaise points to weaknesses and rigidities in Japanese institutions and macroeconomic factors (Hamada & Okada, 2009; Ozawa, 2003). Our analysis of Japan's connectivity to the global innovation system through co-inventor networks adds another plausible contributory factor to the poor performance of the Japanese economy.

This study is organized as follows: the first section explains theoretical backgrounds, with special reference to NSIs and co-inventor connectivity. Subsequently, we describe the research context and data and report our findings. We conclude with a discussion on our findings, and suggest avenues for further research.

3.2. Theoretical Background

3.2.1. National systems of innovation

Within the tradition of evolutionary economics, long-term economic growth is largely explained by knowledge creation and accumulation in the location. The tacit nature of knowledge makes it difficult to transfer knowledge over distance and therefore the knowledge becomes 'sticky' within geographical boundaries. The transfer of such knowledge requires frequent face-to-face interaction between the giver and the recipient of the knowledge (Von Hippel, 1994), and complete comprehension also requires an understanding of the cultural and institutional context within which it was created (Gertler, 2005; Maskell & Malmberg, 1999). Both of these aspects underline the critical importance of physical proximity between the parties involved in the knowledge exchange.

Moreover, knowledge is cumulative in the sense that the existence of certain knowledge in a location provides the trajectory for further development of the knowledge in the future (Dosi, 1988). All these features of knowledge lead to differences in the accumulation of knowledge in different geographies. These differences arise at all levels of aggregation such as cities, regions and nations. Certain city regions like Silicon Valley and Hsinchu become knowledge clusters (Saxenian & Hsu, 2001), towering above their surrounding hinterland in terms of knowledge output and associated entrepreneurial activity. The same pattern can also be observed at the level of the nation state like Israel (Senor & Singer, 2009), so that innovation outcomes and the level of economic advancement differ across geographical space.

The notion of a 'national systems of innovation' was originally developed by Freeman to analyze postwar Japanese economic policy and development (Freeman, 1987), and has been applied to a wide cross-section of countries in various studies (Lundvall, 1992; Nelson, 1993). NSIs are made up of different economic and societal components, defined within the limits of a geographical and economic space. The interaction of these components within the national institutional setting form the foundation for a nation's ability to create knowledge and innovate (Freeman, 1995; Lundvall, 1992). Innovation systems can be defined in different ways: national, regional, sectoral or technological (Carlsson, Jacobsson, Holmén & Rickne, 2002). These levels can be combined; in our case, we capture one important dimension (inventor connectivity) in four key sectors (Malerba, 2002) of the Japanese economy to infer the characteristics of the broader NSI of Japan.

As a consequence, countries exhibit systematic differences in terms of their innovation outcomes, and several empirical studies have shown that the divergence in the abilities of nations to create and utilize technological knowledge leads to the discrepancy in economic development (see for example, Castellacci & Archibugi, 2008; Fagerberg & Srholec, 2008). The way in which firms carry out their innovation activities and implement upgrading processes is heavily affected by a number of national characteristics, including institutions and public policies towards innovation (Cano-Kollmann, Hamilton, & Mudambi, 2016; Nelson, 1993), user-producer interaction and competence building (von Hippel, 1988), the link between innovation strategies of firms and national patterns of accumulation of technological knowledge (Patel & Pavitt, 1991), national inter-industrial networks (Lundvall, 1992), and the specificities of national institutions (Amable, Barre, & Boyer, 1997). Moreover, the institutional set-up of education systems, labor markets, financial markets, intellectual property protection, and welfare systems have been found to influence firms' innovation activities.

Even though there are varied approaches within the NSI framework, each focusing on different aspects (Dosi, 1999), the current literature seems to emphasize the importance of institutions in the process of the creation, diffusion, and utilization of innovation. These include formal aspects such as political, financial, and industrial institutions, and also informal ones like trust and social norms that "affect the capacity of firms to interact and therefore affect the relative transaction and coordination costs of production and innovation" (Mudambi & Navarra, 2002: 636). Johnson (1992) explains that institutions affect the patterns of interaction, which forms the environment for learning. As interactive learning can be critical in economic development process, different institutions rooted within national boundaries (Meyer, Mudambi, & Narula, 2011) will lead to divergences in learning capabilities and, thus, different experiences in economic development.

While the substantial volume of research in this space has helped us to better understand different patterns of shaping technological capabilities across countries and resultant economic development, as Nelson (1993) pointed out, this line of research had traditionally focused on purely domestic or local sources of knowledge. This excludes international and cross-border elements such as FDI (Smeets, 2008), cross-border collaboration (Narula & Santangelo, 2012) and R&D alliances (Narula & Santangelo, 2009), which enable firms to tap into diverse technological knowledge bases created and accumulated by other NSIs. Hence, subsequent research into NSIs explicitly brought in international elements. Exploring the relationship between national institutional context and the development of biotechnology industry in the US, UK, Japan, and Germany, Bartholomew (1997) argued that in the era of globalization, NSIs are interconnected through international or cross-border technological collaboration such as R&D alliances.

Focusing on the case of Japan, Cantwell and Zhang (2006) took a similar approach and investigated the internationalization of technological activity in Japan over the period 1969-1995. They found that Japan exhibited a very low level of R&D internationalization, which they largely attributed to domestic *keiretsu* networks, a deeply embedded institutional feature of the Japanese economy. In a similar vein, Cantwell and Zhang (2009) extensively investigated the Japanese technological catch-up experience by examining international business connections. They found that international business connections and especially FDI had played a significant role for Japanese firms to build their technological capabilities in the early years (from the Meiji restoration in the late 19th century through the 1920s), but as they caught up with advanced countries, their international business connections became closed over time partly due to the relevant government policies aimed at encouraging the technological independence.

3.2.2. Open and Closed NSIs

While many scholars have added international or cross-border components to the NSI literature by looking at various international knowledge sourcing mechanisms, virtually all of these have focused on codified rather than tacit knowledge. Licensing, for instance, had been used as important knowledge transfer mechanism by many less developed countries during the early stages of the industrialization process (e.g., Kumaraswamy, Mudambi, Saranga, & Tripathy, 2012) and is well-known to be more effective for transferring explicit knowledge and mature technologies (Contractor & Ra, 2002). Further, many firms are reluctant to license their new and sophisticated technology to firms that are potential competitors (Mowery & Oxley, 1995).

Interaction with MNCs in buyer-supplier relations is another way that local firms can access new knowledge (Giuliani, Pietrobelli, & Rabellotti, 2005; Humphrey & Schmitz, 2002). However, research has found that it was quite effective for local firms to develop output (imitation) capabilities based on codified knowledge. It is much less effective in developing innovation capabilities (Awate, Larsen, & Mudambi, 2012) that require tacit knowledge.

Unlike these formal knowledge transfer mechanisms, informal knowledge conduits such as co-inventor network have been shown to be effective for tacit knowledge transfer (Agrawal, Cockburn, & McHale, 2006; Breschi & Lissoni, 2009; Fleming & Marx, 2006;). The tacit dimension of knowledge has been defined as that part that is ‘not openly expressed or stored, but implied, understood, inferred (Wong & Radcliffe, 2000), or in the words of Polanyi (1966), ‘knowing more than we can tell’. Tacit knowledge does not derive from theory, but rather from experience, or learning by doing. For that reason, co-inventor networks are a particularly apt vehicle for its transmission.

Co-inventor networks differ from other international knowledge sourcing mechanisms for two reasons. First, co-inventors usually work together for extensive periods of time and maintain contact even after individual projects are completed. The mutual trust developed over time creates a favorable environment of mutual understanding within which tacit knowledge can be transferred (Breschi & Lissoni, 2009). Geographically dispersed co-inventors can further ameliorate the problems of distance through “temporary co-location” in a wide range of events such as trade fairs and conferences, facilitating the tacit knowledge transfer process (Cano-Kollmann, Cantwell, Hannigan, Mudambi, & Song, 2016).

Second, different NSIs develop distinctive technological competencies by leveraging unique knowledge accumulation patterns (Cantwell, 1989; Pavitt 1987). For instance, Germany has traditionally shown technological strength in chemicals and automobiles, whereas Italy has shown technological advantage in textiles. Therefore, companies trying to remain on the competitiveness frontier in those industries will benefit from establishing connections to Germany. Hannigan, Cano-Kollmann and Mudambi (2015) found that the big automakers based in Detroit have over time strengthened their connections to centers of excellence in the auto industry (particularly in Germany, and to a lesser degree in Japan) as a way to reinforce their own innovative capabilities. This connectivity is crucial for catch-up when firms are located in emerging or peripheral regions (Awate, Larsen, & Mudambi, 2012) but it is equally important for firms in developed regions, as the Detroit example shows.

Internationalization implies two distinct problems: finding useful knowledge and transferring it. This is known as the ‘search-transfer problem’ (Hansen, 1999). International integration and knowledge sharing demands substantial strategic commitments to foreign markets, entailing increasing dispersion and duplication of capabilities within individual technologies and the formation of a network of units with full-fledged operations, in addition to well-developed management systems (Zander, 1998). Phene, Fladmoe-Lindquist, and Marsh (2006) also argue that there are differences in terms of the type of knowledge generated and the manner in which this knowledge is created in different national contexts. Further, due to the differences in perspectives and cognition, inventors in different national contexts may utilize the same components of knowledge in quite different ways (Phene et al., 2006). Thus, international co-inventor teams function as bridges across NSIs that can integrate the diverse associated knowledge bases. Working on a certain research project with inventors from a different national context, therefore, increases the chance of accessing new tacit knowledge. The more sophisticated a country's NSI, the greater the importance of sourcing international tacit knowledge and the more its firms would need to be involved in international research collaboration through co-invention.

3.3. Empirical Analysis

3.3.1. Research Context

In this study, we investigate the Japanese NSI in major industries through the lens of co-inventor connectivity. In order to scale the extent of connectedness of the Japanese NSI, we undertook a comparative analysis, using two European economies, Germany and Denmark. Both have a similar level of technological sophistication to Japan using the Global Innovation Index (Dutta, Lanvin, & Wunsch-Vincent, 2015): Japan's overall innovation index in 2015 (53.97) was comparable with that of Germany (57.05) and Denmark (57.70). Our analysis reveals that Japan's overall patent production (1975-2010) is just under 2,100 patents per million population. The corresponding figure for Germany is just over 1,700 and for Denmark it is just over 960. Thus, while Japan's innovation index is slightly lower than the two comparison countries, its per capita patent production is slightly higher.

Specifically, we analyze the co-inventor connectivity of four major industries in Japan: automobiles, electronics, pharmaceuticals, and robotics. We compare the results with similar analyses undertaken for those industries in Germany and Denmark. The industries were chosen to reflect both the strengths and weaknesses of each country's NSI (Dutta, Lanvin, & Wunsch-Vincent, 2015). Both Japan and Germany are world leaders in automobiles, electronics and robotics. Neither is a leader in pharmaceuticals. Denmark is strong in electronics, and pharmaceuticals, but does not occupy a leading position in automobiles or robotics.

The comparison of Japan with Germany and Denmark will help us to understand the position of the Japanese NSI for the following reason: we pick two countries – one of a similar scale to Japan (Germany) along a number of dimensions (population, GDP, land area, innovation output) and one of a very different scale to Japan (Denmark) to see whether the scale itself matters. Japan is the 10th largest country in the world by population, whereas Germany is the 16th and Denmark is 112th respectively. In terms of total land area, Japan is the 61th largest country, followed by Germany, whereas Denmark is placed in 133th (*World Bank*, 2013). It has been suggested that small countries are at a relative disadvantage in innovation, therefore are more open to free trade and international capital flows (Grossman & Helpman, 1991). By showing that even relatively large countries are also open, however, we argue that tapping into other national systems of innovation through co-inventor networks is an imperative for all countries regardless of their size.

3.3.2. Level of Analysis

Our paper discusses the characteristics of the Japanese NSI and therefore we look at the total innovation output of Japan. Our data shows, however, that big Japanese multinationals make up the biggest component of that output. In fact, the top 10 Japanese patent holders in our dataset are all MNEs. These 10 companies account for more than 40% of the country's patent output in our dataset (see Table 10). No universities, research organizations or government institutions appear in this top 10. Therefore, firm-level discussion is key to our arguments because firms are by far the main drivers of innovation within the Japanese NSI.

3.3.3. Data

Our main database consists of patent data collected from the Harvard Dataverse Network. The Harvard Dataverse Network contains patent data at the inventor-level collated from US Patent and Trademark Office (USPTO) and refers to the period of 1975-2010 (Li, Lai, D'Amour, Doolin, Sun, Torvik, Amy, & Fleming, 2014). As the data was originally constructed to study inventor networks and mobility, it is organized by individual inventor. It also contains all other information available on a USPTO patent document including the patent number, technology class, application year, grant year, abstract, patent claims, cited work, assignee name, and assignee location (including GPS coordinates, street address, city, and country).

Despite some criticisms, patents are generally recognized as good indicators of the extent and characteristics of firms' inventive activities, and thus, are frequently used for the analysis of the process of technological change (Griliches, 1990; Awate, Larsen, & Mudambi, 2012; Cantwell & Zhang, 2013). Since electronics, pharmaceutical, automotive, and robotics industries are high-technology industries with active patenting activities (Penner-Hahn & Shaver, 2005), patent-related measures are expected to provide strong insights into innovation activities in these industries.

We extracted electronics, pharmaceutical, automotive and robotics patents using the technology classification suggested by Hall, Jaffe, and Trajtenberg (2001). With this dataset, we identify patents that are connected to Japan, Germany, and Denmark. We do this by identifying the patents that have at least one inventor located in the specific country. The Harvard Dataverse contains patents by application year. Hence, there is a significant truncation problem towards the end of the data series, e.g., very few patents applied for in 2010 have been granted by the end of 2010. Therefore, we limited the data from 1975 to 2004. Our analyzed dataset consists of 406,168 patents. Of these, Japan accounts for 262,206, Germany for 138,560 and Denmark for 5,402. The Japanese NSI is quantitatively heavier in electronics, while the German NSI is weighted toward the automotive sector and the Danish NSI focused on pharmaceuticals (see Table 1).

After identifying the patents, we construct a country dispersion index, following Hannigan, Cano-Kollmann and Mudambi (2015) and Brandl et al. (2015). This measure was calculated as

$$\text{Country dispersion} = 1 - \sum_{i=1}^{N} {s_i}^2$$

where s_i is the share of inventors located in country *i* and *N* is the number of inventor countries that appear in a patent. Conceptually, this measure captures how dispersed inventors are across countries, taking a value between 0 and 1. Simply put, we can say the inventors on a focal patent are more dispersed as the dispersion index increases asymptotically toward 1. This can occur in two ways:

(a) The inventor team on the focal patent is dispersed across a larger number of countries. A patent with one inventor each in two countries is less dispersed than a patent with one inventor each in three countries.

(b) The inventor team on the focal patent is more evenly distributed across countries. A patent with three inventors in one country and one inventor in a second country is less dispersed than a patent with two inventors in each of the two countries.

As can be seen from (a) and (b) above, a patent with a higher dispersion index connects the parent country NSI more widely *and* more deeply to the NSIs of other countries.

3.4. Results

3.4.1. Number of USPTO patents applied by firms in a country by industry

We begin our comparative analysis by presenting the number of patents granted to Japanese, German and Danish assignees by year and by industry. These results are presented in Table 1 and Figures 1, 2 and 3. Comparing the results for the three countries, we find that Japan is the most innovative both in terms of total number of patents (see Table 1) as well as in the number of patents granted longitudinally. In other words, Japan's innovation performance is on par or superior to two of the leading innovative nations of the world.

In Figure 1, we observe that the Japanese electronics industry has an overwhelming number of patents compared with the other three industries: automobiles, robotics and pharmaceutical. In other words, the Japanese NSI is particularly strong in electronics and this industry has a significant share of overall Japanese patent output. Japan has traditionally shown technological leadership in the electronics industry (Cantwell & Zhang, 2009) and our findings confirm this.

Further, Japanese firms continue to be global innovation leaders in terms of the gross number of patents produced. Examining the top thirty firms worldwide in terms of patents granted by the USPTO, we find that thirteen are Japanese (see Table 2). Of these, eleven are wholly or partially focused on electronics. This table encapsulates the puzzling questions that motivate this paper: why has the Japanese economy performed so poorly in recent decades when the Japanese NSI continues to produce a higher output of innovation than almost any other economy in the world? And why have Japanese firms lost their competitiveness in several industries, when they remain world leaders in terms of the production of innovation?

Proceeding to the case of Germany, it is not surprising that the automobile industry has produced the largest number of patents since 1975 (see Table 1), since Germany accounts for roughly two thirds of the European R&D spending in auto technologies (Pavlínek, 2012). However, in Figure 2, we present a longitudinal analysis and see that by the early years of the 21st century, the electronics industry was beginning to match the automobile industry in terms of patent output. The German pharmaceutical industry shows steady increase in patent output in the 20th century, but begins to fade in the new century. Robotics remains a relatively minor part of the German NSI.

As we noted above, Denmark is the smallest of three countries and hence the number of patents it produced is significantly smaller. Its strongest innovation output occurs in pharmaceuticals. The innovation output of its automobile and electronics industries has been rising on a secular basis. However, there is relatively little in terms of robotics innovation in the country's NSI.

3.4.2. Co-inventor connectivity

Next, we explore co-inventor connectivity which allows firms in one country to tap into tacit knowledge developed within other national systems of innovation. The country dispersion indices of the Japanese, German and Danish patents in the automobile, electronics, pharmaceutical and robotics industries are presented in Tables 3, 4, and 5.

As seen from the tables, the absolute value of the dispersion index over all four industries in Japan is approximately one-tenth of that in Germany and Denmark. This suggests that the Japanese NSI is less connected to the NSIs of the other countries and, compared to the German and Danish NSIs, i.e., it is substantially closed. Among the four industries in Japan, the dispersion index of the pharmaceutical industry is highest with (0.038: 1995-2004). Even though its absolute value is low, the dispersion index of Japanese patents in the pharmaceutical industry has indeed increased rapidly over the past three decades, although from an extremely low base.

Germany also has the highest dispersion index of (0.151: 1995-2004) in the pharmaceutical industry. The electronics industry (0.081: 1995-2004) follows the pharmaceutical industry, and then the automobile and the robotics industries (0.063 and 0.052: 1995-2004) follows. Thus, the dispersion indices of German patents in technology-intensive industries such as automobile, electronics, pharmaceutical and robotics are much higher than those of Japanese patents in the same industries and increase at faster rates.

The Danish pharmaceutical industry has the highest dispersion index of (0.150: 1995-2004), which is the same pattern as in Japan and Germany. However, the robotics industry has the second highest dispersion index of (0.141: 1995-2004). Interestingly, the dispersion indices of both industries have grown rapidly, whereas the electronics industry has declined. Overall, Denmark shows a higher level of the dispersion index than the two larger economies, which is to be expected considering smaller countries have less deep pools of knowledge and therefore may be more compelled to build external linkages.

We further mapped these results into the graphs by industry. This enables us to examine industry-wise differences across the three country NSIs. As seen in Figure 3 we present results for the automobile industry. Japanese patents show the lowest level of co-inventor connectivity throughout the entire sample period, dramatically lower than that of the other two countries. Although co-inventor connectivity of German patents is slightly lower than that of Danish patents, it has increased at a faster pace since 1994.

We observe a similar pattern in Figure 4 where we compare the patents of each country in the electronics industry. Again, Japanese patents show the lowest level of co-inventor connectivity throughout the sample period, and the co-inventor connectivity of German patents increases rapidly from 1994. Co-inventor connectivity of Danish patents increases steadily, showing values very close to those of Germany, always much higher than those of Japanese patents.

In Figure 5, we present results for the pharmaceutical industry. In common with the automobile and electronics industries, Japanese patents show the lowest level of co-inventor connectivity for the entire sample period, whereas the co-inventor connectivity of German and Danish patents has increased rapidly. Finally, in Figure 6, we present results for the robotics industry. Once again, Japanese patents show the lowest level of co-inventor connectivity for the sample period, while German and Danish patents show increasing co-inventor connectivity over time.

The detailed analysis of the dispersion indices of inventors in Japan, Germany and Denmark, reveals that values for Japan are overwhelmingly low in all four major industries. This indicates that the Japanese system of innovation is substantially closed. In other words, its access to tacit knowledge in other NSIs through co-inventor connectivity is very limited compared with other economies. Our comparative analysis seems to indicate that this is not related to country size, since we compared it both to a large economy as well as a small open economy.

Finally, we present results on the inventor locations that appear in the overall patent portfolio of each of our three countries in each of the four industries analyzed in this paper. These results are presented in Tables 6 through 9. Obviously, the majority of inventors appearing in any country's patent portfolio are located in the focal country. However, the extent to which foreign-located co-inventors appear in a country's patent portfolio is a cruder, but more direct measure of the cross-border sourcing of tacit knowledge.

Given our earlier results based on the more sophisticated measure of dispersion index, it is not surprising that we observe that Japan shows the highest concentration of home-based inventors in its patent portfolio in all four industries. Specifically, in the case of Germany and Denmark, even though the majority of collaborators come from their own country, the degree of concentration is lower than that of Japan. As an example, the percentage of foreign inventors in the electronics industry is roughly eight times higher in

Germany (8.31%) than in Japan (1.05%). The same is true for the auto industry, where the percentage of foreign inventors in Germany is seven times higher than in Japan (4.94% vs. 0.75%). Further, foreign co-inventors in the patent portfolios of Germany and Denmark are dispersed over a wider range of countries as compared to Japan.

3.5. Discussion and Concluding remarks

This study investigates the Japanese NSI through the lens of co-inventor connectivity. Specifically, using the comprehensive 30-year data set of USPTO patents, we analyze the extent to which the Japanese NSI is connected to the global innovation system by comparing it to its German and Danish counterparts in four representative industries. Our results clearly show that Japan has produced an impressive number of patents over the last three decades, a result that is consistent with the country's extremely high spending on R&D, both in terms of total expenditure as well as in terms of R&D intensity. However, it is not well connected to other national innovation systems, at least through co-inventor connectivity. This leads us to conclude that the Japanese system of innovation is quite closed. In other words, Japanese firms rely heavily on the local Japanese NSI to develop the innovation capabilities that underpin their competitive advantage. Our analysis reveals that, the NSIs of other comparably advanced economies such as Germany and Denmark are significantly more connected to the global innovation systems through co-inventor connectivity. Further, we even find that both these European economies have become more connected in almost all industries in recent years.

This finding is quite interesting. Japan's leading global position in terms of innovation inputs and outputs is well known: Japan is the world's third largest R&D spender after the U.S. and China (Riemschneider, 2016), with a long term R&D / GDP ratio of about 3 percent, (see Figure 7). In fact, Japan has shown both high innovation input (R&D expenditure) and output (the number of patents granted) for many decades. However, the comparative isolation of the Japanese NSI, especially in the context of co-inventor connectivity, leads us to suggest that this characteristic may be one of the causes for the country's failure to emerge from its decades' long period of economic underperformance. It also raises questions about the competitiveness of the Japanese economy (and Japanese MNEs) in the future.

Japan's unusually low degree of R&D internationalization has been widely documented (e.g., Cantwell & Zhang, 2006; 2009; Guellec & Van Pottelsberghe de la Potterie, 2001). Many scholars have called for Japan to open up to international interaction to stimulate innovation in the country (Cantwell & Zhang, 2009; Ozawa, 2003). As Cantwell and Zhang (2006: p. 252) put it: "Japan's economy and society have become locked in to a certain set of institutional arrangements, which in turn have become incompatible with the new world trend towards international networks for innovation". Reflecting this, more recent evidence suggests that institutional lock-in may be sowing the seeds of future perils. Once a world leader, the Japanese automobile industry floundered over the last decade. Nissan struggled and eventually had to be rescued by entering into a joint venture with Renault. Daihatsu has been acquired by Toyota. Mitsubishi and Mazda have produced consistently anemic returns (Hagiwara, Trudell, & Jie, 2016). The Japanese electronics industry has been struggling in recent years as well, leading to worsening losses in their core businesses (*The Economist*, 2014). Erstwhile titans like Sony and Hitachi are struggling in competition with upstarts like

Samsung (Chang, 2008). The weak performance of a wide range of Japanese industries comes in spite of the country's Herculean innovative efforts.

These arguments imply that the strength of a NSI stems both from its internal characteristics as well as its connectivity to the global innovation system (Bathelt et al., 2004; Lorenzen & Mudambi, 2013). No country, no matter how strong its innovative capabilities, can sustain the competitiveness of its constituent firms without leveraging global competencies (Narula, 2002). Indeed, drawing on multiple sources of knowledge is key to the health of an NSI (Fagerberg & Srholec, 2008; Freeman, 1995; Lundvall, Johnson, Andersen, & Dalum, 2002). Thus, it is reasonable to think that even though Japanese firms can depend on excellent innovative resources and competencies in their home environment, they cannot sustain their competitive advantage in the long run against competitors who tap into a much wider range of innovative systems in the world. This is particularly true in the modern knowledge economy where firms must compete within a business environment where radical innovations and technological discontinuities often take place (Mudambi & Swift, 2014) and stem from a diversity of locations (Cantwell & Mudambi, 2005).

As seen from our analysis, we have identified one critical missing component in the Japanese NSI – co-inventor connectivity that allows firms access to the most tacit knowledge and capabilities in the global innovation system. Investing in R&D enables a firm to build the ability to better use externally available knowledge (Hannigan et al., 2015). However, without a constant influx of new ideas and knowledge, particularly those of a tacit nature that flow in through co-inventor networks, it may not be enough to sustain a country's competitiveness. In other words, Japan may not be able to sustain its competitiveness unless it opens to the global innovation system and begins to actively source diverse knowledge. Hence, we suggest that it is important for Japan to overcome its co-inventor insularity and make an effort to be connected to the global innovation system for it to emerge from its economic recession and prosper again.

It is important to recognize that the strategies to achieve a higher level of co-inventor connectivity need not involve increasing reliance on foreign firms or institutions. For most countries, the largest component of international co-inventor connectivity stems from the location of R&D activities within the foreign subsidiaries of their own MNEs. Japanese MNEs already run significant R&D operations in most major knowledge clusters of the world. The building blocks for international co-inventor connectivity are already in place. Therefore, the challenge appears to be more one of culture and organization rather than strategy (Asakawa, 2001).

As an island nation far removed for many decades from any other technologically advanced countries, Japan's knowledge creation and innovation culture is quite unique and inward looking. For instance, Japanese innovators believe deeply in the concept of "ba" that holds that knowledge cannot be separated from context (Nonaka & Konno, 1998). This makes them unwilling to move R&D processes to foreign subsidiaries that are embedded in unfamiliar contexts. Further, Japanese innovation design philosophy is based on kei-haku-tan-sho (light, thin, short, small), an approach that is driven as much by form as by function (Takeuchi, 1991). This approach, especially when married to a strong historical reliance on continuous improvement, as seen in the Toyota "kanban" system (Ohno, 1988) tends to be biased toward incremental innovation and away from novel exploratory ideas stemming from foreign NSIs.

Beyond cultural challenges, the organizational challenges of moving beyond centralized innovation systems are well documented. They include the not-invented-here (NIH) syndrome (Katz & Allen, 1982), power politics within the organization (Mudambi & Navarra, 2004; Pfeffer, 1990) and concerns about the integration of diverse knowledge bases within a multiple embedded MNE (Meyer, Mudambi, & Narula, 2011). Beyond technological blinders and strategic jockeying, some organizational challenges may arise simply because managers have limited bandwidth (Narula, 2014).

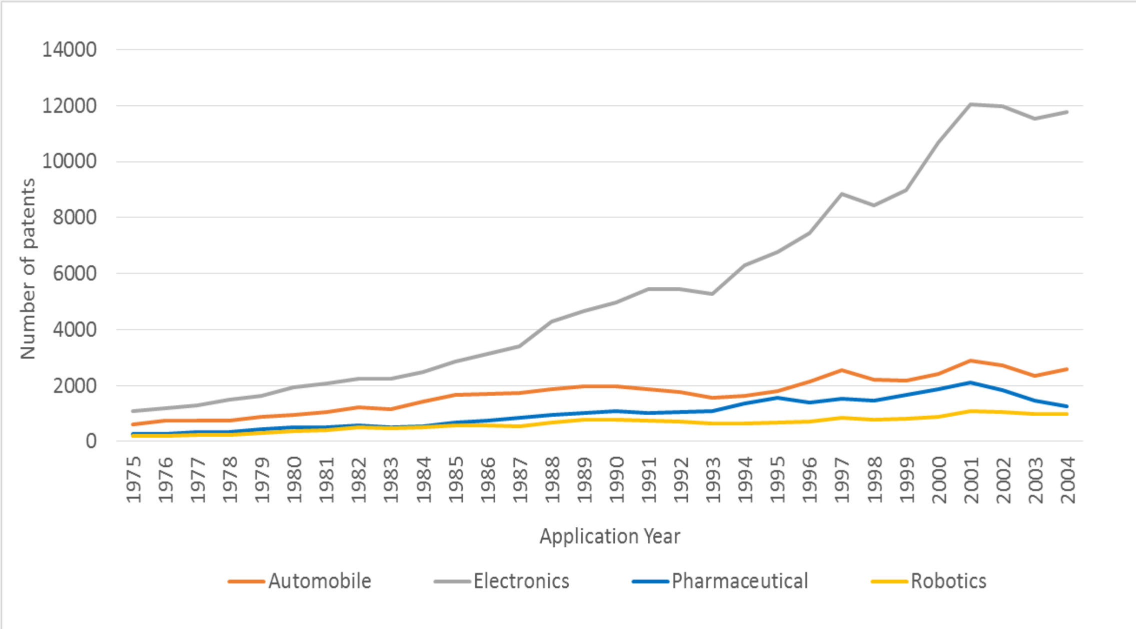
One limitation of our paper is that we are looking at the Japanese NSI with aggregate patent data, but we do not look at particular sectors like universities, government agencies or research organizations. Also, while our analysis points toward the closedness of the Japanese NSI, it is possible that its connectedness to the global innovation system may not be fully captured by our measure. There are mechanisms of international technology transfer and learning that will not be detected in our measures. International research collaborations are the typical tacit knowledge transfer mechanisms that encourage more geographically dispersed innovation activities. However, technologies can also be transferred through mechanisms such as the movement of people who return from immersions within foreign innovation systems. These could be managers and scientists returning from postings within foreign subsidiaries of Japanese MNEs or students returning after completing their education in foreign universities. Hence, a useful avenue for future research would be to complement our study by examining other knowledge transfer mechanisms to see if there are other ways through which tacit knowledge flows into and diffuses in the Japanese NSI.

Table 3.1: Overall Patent Dataset*

	Japan	Germany	Denmark	Total
Automobiles	51045	65400	1515	117960
Electronics	161945	44105	1166	207216
Pharma	30280	23018	2650	55948
Robotics	18936	6037	71	25044
Total	262206	138560	5402	406168
Population	127.30	80.62	5.61	
Patents / million population	2079.75	1718.68	962.24	

Source: Harvard Dataverse

Figure 3.1: Number of USPTO Patents Applied by Japanese Firms by Industry

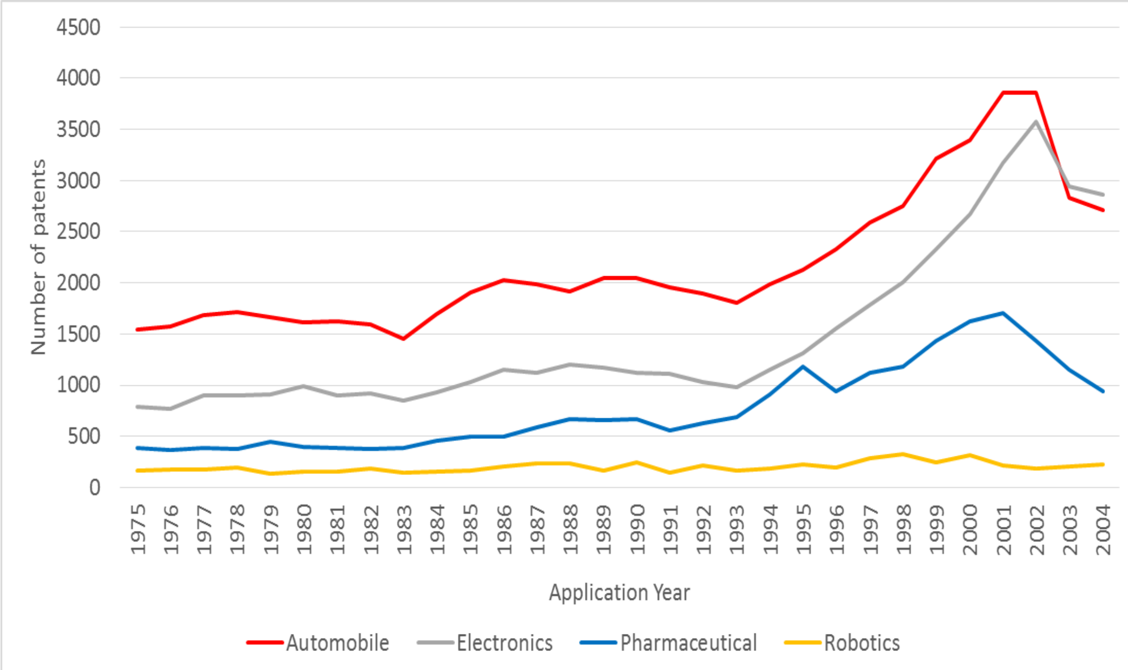


Source: Authors' analysis of U.S. Patent and Trademark Office data

Table 3.2: 2013 Top 30 US Patent Assignees in the electronics industry

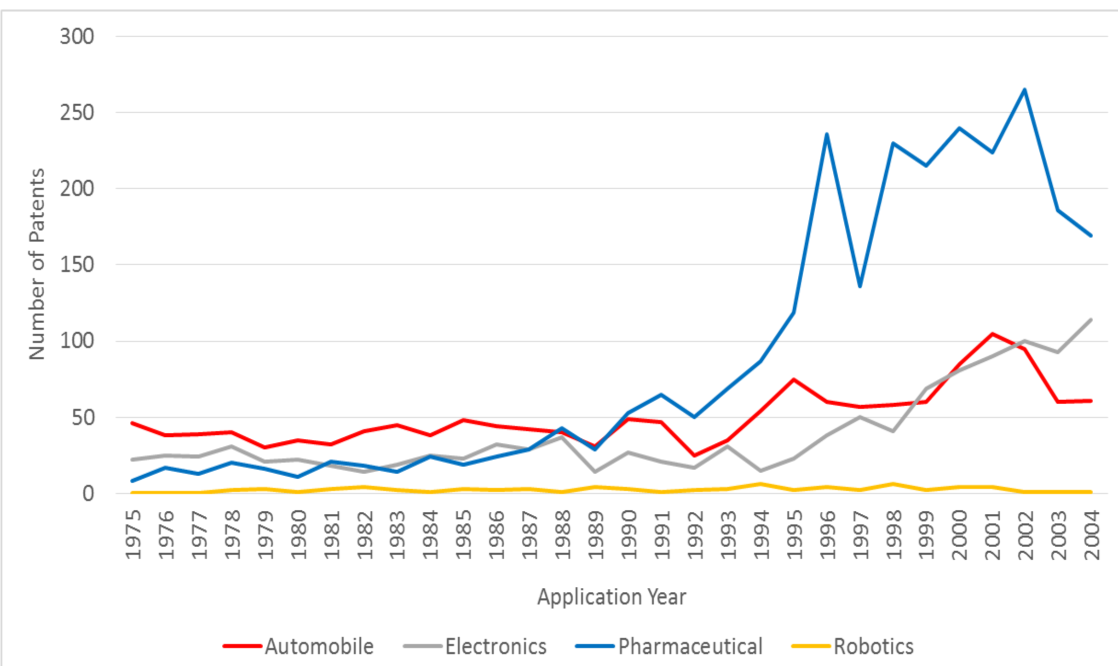
Rank	Assignee Name	Country	Grants
1	IBM	US	6788
2	Samsung Electronics Co. Ltd.	South Korea	4652
3	**Canon Inc.**	Japan	3820
4	**Sony Corporation**	Japan	3073
5	Microsoft Corporation	US	2659
6	**Panasonic Corporation**	Japan	2582
7	**Toshiba Corporation**	Japan	2365
8	Qualcomm Inc.	US	2103
9	LG Electronics Inc.	South Korea	1945
10	Google Inc.	US	1851
11	**Fujitsu Limited.**	Japan	1802
12	Apple, Inc.	US	1775
13	General Electric Company	US	1737
14	GM Global Technology Operations LLC	US	1621
15	**Seiko Epson Corporation**	Japan	1488
16	**Ricoh Company, Ltd.**	Japan	1469
17	Intel Corporation	US	1454
18	Hewlett-Packard Company.	US	1358
19	Samsung Display Co., Ltd.	South Korea	1259
20	**Toyota Motor Corporation**	Japan	1171
21	Ericsson	Sweden	1149
22	**Sharp Corporation**	Japan	1113
23	AT&T Inc.	US	1099
24	**Hitachi, Ltd.**	Japan	1096
25	Broadcom Corporation	US	1083
26	**Honda Motor Co., Ltd**	Japan	1070
27	**Semiconductor Energy Laboratory Co., Ltd.**	Japan	1033
28	**Brother Industries, Ltd.**	Japan	1026
29	Micron Technology, Inc.	US	1019
30	Xerox Corporation	US	1008

Figure 3.2: Number of USPTO Patents Applied by German Firms by Industry



Source: Authors' analysis of U.S. Patent and Trademark Office data

Figure 3.3: Number of USPTO Patents Applied by Danish Firms by Industry



Source: Authors' analysis of U.S. Patent and Trademark Office data

Table 3.3: Co-inventor connectivity in Japan

	Automobile		Electronics		Pharmaceutical		Robotics	
Year	# of patents	Mean	# of patents	Mean	# of patents	Mean	# of patents	Mean
1975-1984	9531	0.001	17719	0.002	4275	0.013	3380	0.002
1985-1994	17734	0.003	45746	0.005	9844	0.022	6716	0.004
1995-2004	23780	0.006	98480	0.008	16161	0.038	8840	0.009
Total	51045	0.003	161945	0.005	30280	0.024	18936	0.005

Source: Authors' analysis of U.S. Patent and Trademark Office data

Table 3.4: Co-inventor connectivity in Germany

	Automobile		Electronics		Pharmaceutical		Robotics	
Year	# of patents	Mean	# of patents	Mean	# of patents	Mean	# of patents	Mean
1975-1984	16169	0.021	8845	0.023	3957	0.040	1659	0.010
1985-1994	19565	0.037	11065	0.045	6354	0.081	1968	0.027
1995-2004	29666	0.063	24195	0.081	12707	0.151	2410	0.052
Total	65400	0.040	44105	0.049	23018	0.090	6037	0.029

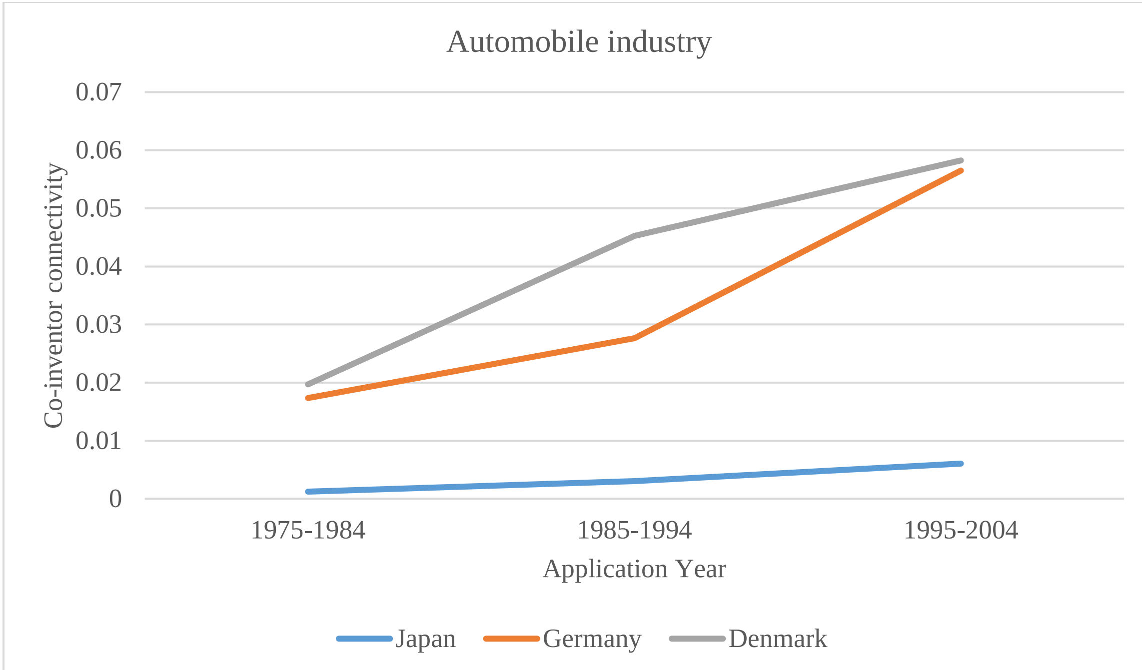
Source: Authors' analysis of U.S. Patent and Trademark Office data

Table 3.5: Co-inventor connectivity in Denmark

	Automobile		Electronics		Pharmaceutical		Robotics	
Year	# of patents	Mean	# of patents	Mean	# of patents	Mean	# of patents	Mean
1975-1984	384	0.022	221	0.026	162	0.055	16	0.008
1985-1994	415	0.050	246	0.081	468	0.091	28	0.062
1995-2004	716	0.061	699	0.070	2020	0.150	27	0.141
Total	1515	0.044	1166	0.059	2650	0.098	71	0.070

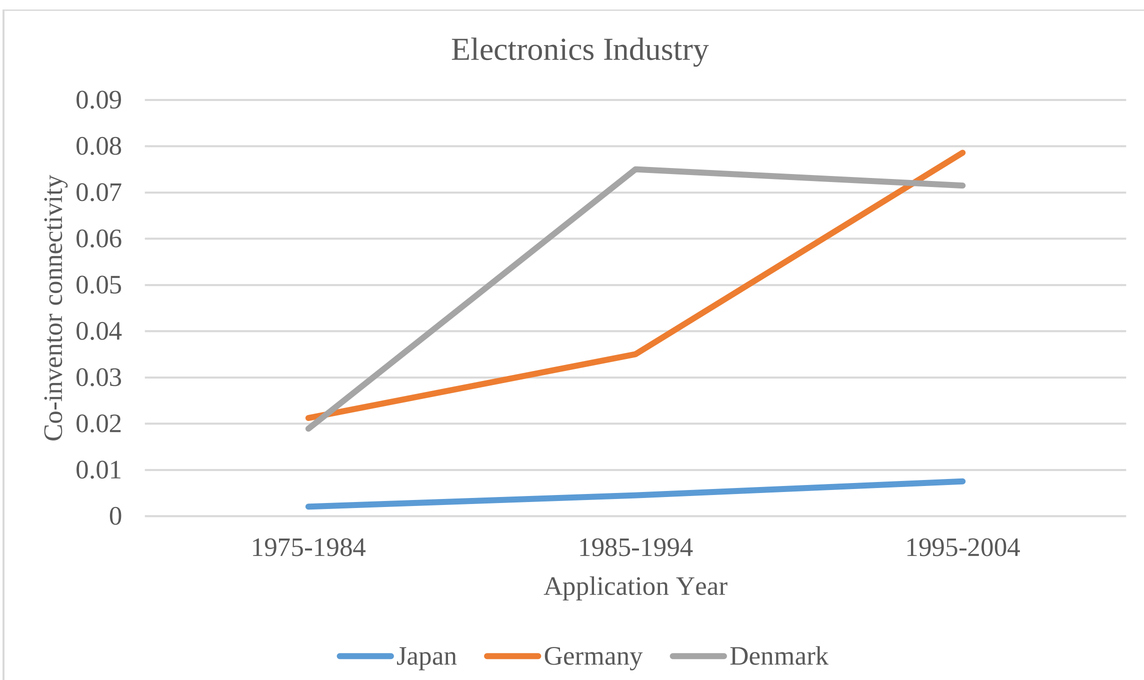
Source: Authors' analysis of U.S. Patent and Trademark Office data

Figure 3.4: Co-inventor connectivity of each country in automobile industry



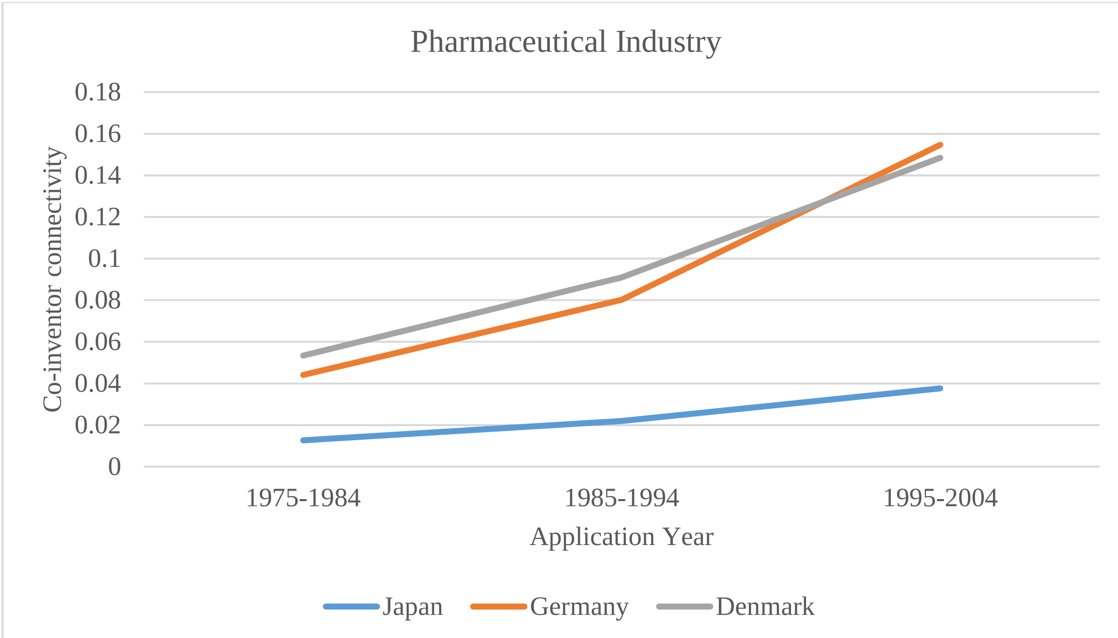
Source: Authors' analysis of U.S. Patent and Trademark Office data

Figure 3.5: Co-inventor connectivity of each country in electronics industry



Source: Authors' analysis of U.S. Patent and Trademark Office data

Figure 3.6: Co-inventor connectivity of each country in pharmaceutical industry



Source: Authors' analysis of U.S. Patent and Trademark Office data

Figure 3.7: Co-inventor connectivity of each country in robotics industry

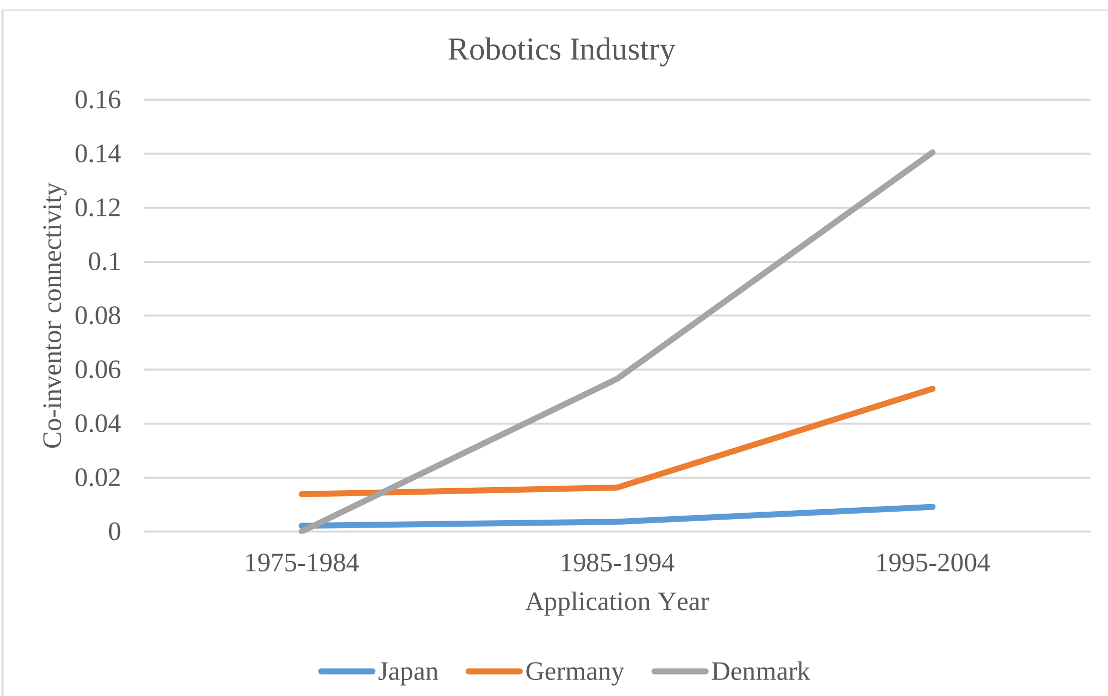


Table 3.6: Top 10 collaborating countries of each country in automobile industry

Japan		Germany		Denmark	
Country	# of inventors	Country	# of inventors	Country	# of inventors
Japan	424717 (99.25%)	Germany	146355 (95.06%)	Denmark	2342 (87.45%)
US	2237 (0.52%)	US	3114 (2.03%)	US	185 (6.91%)
Germany	285 (0.06%)	Switzerland	850 (0.55%)	Germany	54 (2.01%)
France	104 (0.03%)	Austria	623 (0.41%)	UK	16 (0.60%)
UK	89 (0.02%)	France	579 (0.38%)	Sweden	15 (0.56%)
Korea	78 (0.01%)	The Netherlands	418 (0.27%)	France	13 (0.49%)
Canada	62 (0.01%)	UK	403 (0.26%)	The Netherlands	12 (0.34%)
China	44 (0.01%)	Japan	293 (0.19%)	Italy	9 (0.34%)
Australia	43 (0.01%)	Belgium	184 (0.12%)	Norway	7 (0.26%)
Belgium	34 (0.007%)	Italy	169 (0.11%)	Switzerland	6 (0.22%)
Taiwan	33 (0.007%)	Sweden	127 (0.08%)	Canada	4 (0.15%)

Table 3.7: Top 10 collaborating countries of each country in electronics industry

Japan		Germany		Denmark	
Country	# of inventors	Country	# of inventors	Country	# of inventors
Japan	407749 (98.95%)	Germany	108269 (91.69%)	Denmark	2237 (84.67%)
US	3130 (0.76%)	US	5009 (6.98%)	US	196 (7.42%)
Germany	263 (0.06%)	Switzerland	918 (0.78%)	Sweden	37 (1.40%)
UK	233 (0.06%)	The Netherlands	743 (0.63%)	Germany	35 (1.33%)
Korea	152 (0.04%)	Austria	607 (0.51%)	UK	24 (0.91%)
Taiwan	82 (0.02%)	France	449 (0.38%)	Israel	19 (0.72%)
France	69 (0.02%)	Japan	349 (0.30%)	The Netherlands	16 (0.61%)
Canada	60 (0.01%)	UK	337 (0.29%)	Switzerland	12 (0.46%)
The Netherlands	50 (0.01%)	Belgium	270 (0.23%)	Finland	12 (0.46%)
Switzerland	44 (0.01%)	Italy	150 (0.13%)	Australia	10 (0.38%)
Singapore	39 (0.01%)	Canada	111 (0.09%)	Belgium	8 (0.30%)

Table 3.8: Top 10 collaborating countries of each country in pharmaceutical industry

Japan		Germany		Denmark	
Country	# of inventors	Country	# of inventors	Country	# of inventors
Japan	111366 (95.00%)	Germany	74577 (88.94%)	Denmark	7631 (77.55%)
US	3976 (3.39%)	US	5554 (6.25%)	US	854 (8.68%)
Germany	614 (0.52%)	Switzerland	2702 (3.05%)	Germany	340 (3.46%)
UK	230 (0.19%)	France	1410 (1.59%)	Sweden	291 (2.96%)
Canada	176 (0.15%)	UK	667 (0.75%)	The Netherlands	120 (1.22%)
Switzerland	118 (0.10%)	Austria	593 (0.67%)	Czech Republic	111 (1.13%)
France	114 (0.09%)	Japan	522 (0.59%)	UK	105 (1.01%)
Korea	79 (0.06%)	The Netherlands	412 (0.46%)	Japan	66 (0.67%)
Denmark	74 (0.06%)	Italy	285 (0.33%)	Norway	47 (0.48%)
China	72 (0.06%)	Belgium	254 (0.29%)	Canada	38 (0.39%)
The Netherlands	59 (0.05%)	Denmark	251 (0.29%)	France	37 (0.38%)

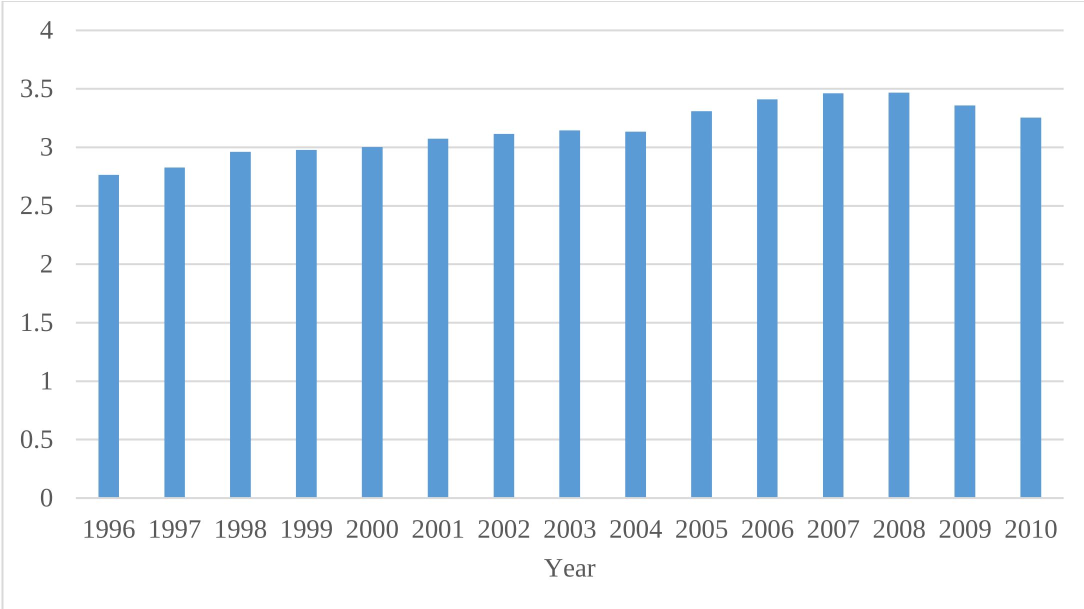
Table 3.9: Top 10 collaborating countries of each country in robotics industry

Japan		Germany		Denmark	
Country	# of inventors	Country	# of inventors	Country	# of inventors
Japan	37296 (98.48%)	Germany	5573 (87.05%)	Denmark	95 (83.33%)
US	420 (1.11%)	US	1543 (2.35%)	US	4 (3.51%)
Denmark	27 (0.07%)	Switzerland	501 (0.78%)	Germany	3 (2.63%)
UK	27 (0.07%)	France	265 (0.41%)	Sweden	3 (2.63%)
Australia	22 (0.06%)	UK	243 (0.38%)	UK	2 (1.75%)
France	20 (0.05%)	Belgium	216 (0.33%)	Norway	2 (1.75%)
Sweden	20 (0.05%)	Austria	213 (0.33%)	Japan	1 (0.87%)
The Netherlands	15 (0.04%)	The Netherlands	169 (0.26%)	France	1 (0.87%)
Switzerland	12 (0.03%)	Japan	167 (0.26%)	The Netherlands	1 (0.87%)
Germany	12 (0.03%)	Italy	80 (0.12%)	Belgium	1 (0.87%)
Hong Kong	10 (0.02%)	Sweden	74 (0.12%)	Switzerland	1 (0.87%)

Table 3.10: Top 10 Patent Assignees in Japan

Assignee	Number of Patents	Percentage
Hitachi	17523	6.68%
Mitsubishi	16595	6.33%
Toshiba	16347	6.23%
Toyota	11012	4.20%
Canon	9960	3.80%
Sony	9571	3.65%
Fujitsu	8088	3.08%
Honda	7083	2.70%
Nissan	6042	2.30%
Mitsui	4253	1.62%
Total	106474	40.59%

Figure 3.8: R&D Spending (as % of GDP) in Japan



Source: World Bank. World Development Indicators

CHAPTER 4: TECHNOLOGICAL FOCUS AND CONNECTIVITY: EVIDENCE OF NEWLY INDUSTRIALIZED COUNTRIES IN EAST ASIA

4.1. Introduction

East Asia's catch-up in the electronics industry during the late twentieth century is remarkable (Hobday, 1995). The successful catch-up story of South Korea (hereafter referred to as Korea) and Taiwan, in particular, is quite impressive given the fact that as recently as the early 1960s, the GDP per capitas of these countries were even lower than those of some African countries, and the majority of the developing countries made little progress in catching up during this period. Both Korea and Taiwan had achieved developed status more than a decade ago. Both counries' innovation systems are mature and exhibit the characteristics of advanced economies. Objectively, by the second decade of the twenty-first century, innovation catch-up has occurred in both these cases.

In Korea and Taiwan, the electronics industry, in particular, has been a backbone of the economy. Many firms in these economies made a successful transition from being simple imitators to innovators (Amsden, 2003; Chang, Pan, & Yu, 2008; Hobday, 1995). Indeed, Korean firms have established world-leading market shares in the electronics industry (Lee & Lim, 2001; Mundy, 2013), becoming a home to global companies such as Samsung Electronics and LG. Similarly, Taiwan is a home for global companies such as Acer, Foxconn Technology Group, and HTC (Chang, Pan, & Yu, 2008).

Catch-up in this industry was mainly attributed to participation in the global production networks which makes it possible for technologically and managerially backward local firms to acquire know-how and technologies from advanced economies.

An early integration into global production networks provided local firms with new opportunities and incentivies to upgrade their technological and managerial capabilities (Ernst & Kim, 2002). The positive role of advanced economy multinational enterprises (AMNEs) as an important transmitter of knowledge has been widely recognized in the current literature (Ivarsson & Alvstam, 2005; Kogut & Zander, 1993; Patibandla & Petersen, 2002).

In discussing catch-up and capability building, Awate, Larsen, and Mudambi (2012) made a distinction between output capability and innovation capability. Defined as technologies and skills related to existing products and services, output capability is relatively easy to develop for latecomer economies through imitation. On the other hand, catching up with innovation capability is much harder to achieve as it requires diverse sets of knowledge and involves more complex processes to manage for less advanced economies (Awate et al., 2012). Through the close interaction with multinational enterprises in the global production networks as mentioned above, firms in the developing economies get exposed to advanced knowledge primarily in the realm of manufacturing (Navas-Aleman, 2011), which allows them to catch up in output capability. Further developing technological capabilities to catch up with innovation capabilities is found to be more challenging for many developing economies.

As global linkages (mostly to advanced economies) provide opportunities for sourcing advanced knowledge and learning, the connectivity of a developing economy, connoted as the bredth and nature of a location's linkage to another location (Lorenzen & Mudambi, 2012), is particularly relevant to study in relation to the process of catch-up in innovation capability. Linkages that involve personal interaction, which facilitates the transfer of tacit knowledge, will be utmost beneficial for building innovation capability. Thus, we study the global linkages created through co-inventor networks, which are based on personal interaction, in the context of innovation catch-up of Korea and Taiwan.

Korea and Taiwan as newly industrialized economies showed a distinctive innovation catch-up pattern. In the fast-paced electronics industry, they needed to overcome a late-mover disadvantage and catch up with technological development in the industry within a short period of time. Both countries developed their technological capabilities and establish themselves as innovators in the global market quickly by focusing on emerging technologies in niche markets. By concentrating on the industry with short technology life cycle, they did not have to devote significant time in learning and catching-up with established technologies and could introduce new products in the new emerging market (Lee, Lim, & Song, 2005).

Interestingly, our analysis shows that despite the remarkable development in their innovation capability over the past three decades, these two countries are not well-connected to the rest of the world. When it comes to patenting, the firms in Korea and Taiwan seem to depend heavily on internal sources of knowledge as the geographic dispersion of the inventors is very low in these countries. We further found that there is a positive relationship between focusing on emerging technologies with short cycle time and the extent to which firms rely on sourcing external knowledge globally. Also, due to the different characteristics of business groups in these countires derived from different institutional contexts, Korean business groups and Taiwanese business groups show quite different inclination on sourcing knowledge globally. Specifically, compared to

Taiwanese business groups, Korean business groups tend to rely less on global knnowledge sourcing.

Our contributions are threefold. First and foremost, we present findings that challenge the conventional belief that late-comer economies are likely to depend more on global connectivity in developing innovation capabilities and propose an alternative path to achieve economic catch-up, more specifically innovation catch-up, that Korea and Taiwan pursued in their catch-up processes. In doing so, we advance discussion on technological capability building of late-comer economies by directing our focus on catch-up in innovation capabilities specifically. Even though a few recent studies have touched upon technological development in less developed countries, they have discussed technological capabilities in a much broader sense without distinguishing output capability and innovation capability, which, we argue, are two distinctive capabilities that require different underlying mechanisms for catch-up (e.g., Lall, 1992; Lee & Lim, 2001; Lee, Song, & Kwak, 2015; Mathews, 2002). Secondly, we bring in a new perspective to the empirical investigation of catch-up process. A large volume of catch-up literature has documented a wide range of factors contributing to successful catch-up such as government policy, participation in global value chains of multinational enterprises from advanced economies and so on, but co-inventor connectivity has not been studied in the context of catch-up of emerging economies (Giuliani, Martinelli, & Rabellotti, 2016). This is quite surprising given that international connectivity through co-inventor network provides channels for transferring the tacit aspects of knowledge (Hannigan, Cano-Kollmann, & Mudambi, 2015) which is critical to developing innovation capability. Our analysis of co-inventor connectivity addresses this critical missing perspective in the literature. Lastly, we direct focus on the role of business groups in the catch-up process and highlight the differences in openness of business groups in the two countries, which has received little attention in the literature despite the substantial contribution of the business groups to economic development of these countries.

The rest of this paper proceeds as follows. The next section provides theoretical background and presents our hypotheses. The following sections provide an overview of our data. We then describe our empirical methodology. We provide empirical results in the next section and conclude with a discussion and conclusion.

4.2. Theoretical Background

4.2.1. Catch-up and capability building through global connectivity

An economy's technological capabilities have been emphasized as a determining factor for heterogeneous development paths observed across countries (Bell & Pavitt, 1997; Castellacci, 2008; Freeman, Clark, & Soete, 1982; Fu, Pietrobelli, & Soete, 2011; Gerschenkron, 1962; Verspagen, 1991). In line with this, the literature on economic catch-up highlighted the importance of developing technological capabilities in reducing the gap between advanced economies and less-advanced economies (Abramovitz, 1986; Kim, 1997). According to Kim (1997), the economic progress in Korea was mainly attributed to its 'technological capability', which he defines as "the ability to make effective use of technology in production, investment, and innovation (p358)." It is also acknowledged that, the greater the gap in technology and productivity between emerging and advanced economies, the greater the potential for emerging economies to realize "rapid" catch-up (Abramovitz, 1986). In other words, the marginal effects of the technologies on productivity and growth are greater for emerging economies than for advanced economies (Hannigan, Lee, & Mudambi, 2013).

In discussing technological development and catch-up, one can further distinguish between catch-up in output capabilities and innovation capabilities (Awate et al, 2012). Output capabilities are primarily related to manufacturing excellence and refer to firms' technologies and skills for producing currently observable product or service, whereas innovation capabilities are the abilities to enhance existing products/services or develop new products and services. Awate et al. (2012) further argue that firms in emerging economies can achieve output capabilities at a relatively fast pace through imitation based on imported technologies. Innovative capabilities, on the other hand, cannot be acquired readily through imitative strategy, as it requires accumulation of more broad sets of knowledge and involves more socially complex processes. Catch-up therefore tends to happen in a sequential process in that local firms first catch up with output capability and then innovation capability later on.

In the process of catch-up, connectivity has been recognized as an important mechanism for learning for firms in the late-comer economies. According to Lorenzen and Mudambi (2012), connectivity connotes the breadth and nature of a location’s linkages to other locations. Be it the level of individuals, organizations or regions, connectivity is represented in the linkages where interaction for knowledge sharing and learning can take place. In local firms’ output capability building, connectivity is often manifested as being part of value chains of advanced economy multinational enterprises (AMNEs). A substantial volume of the global value chain (GVC) literature notes that AMNEs are a main transmitter of knowledge, particularly technological know-how that is difficult to codify (Ivarsson & Alvstam, 2005; Kogut & Zander, 1993; Patibandla & Petersen, 2002). Engaging in AMNEs' value chain network across locations, latecomer firms can upgrade skills and capabilities through interaction with AMNEs in the buyer-supplier relations (Giuliani, Pietrobelli, & Rabellotti, 2005; Humphrey & Schmitz, 2002). Giuliani et al. (2005), for instance, showed how domestic firms in Latin America upgraded their capabilities by supplying their global buyers. Receiving extensive technological assistance from AMNEs helps "technologically backward" and "managerially backward" local firms to develop certain output capabilities (Awate et al., 2012).

In a similar vein, focusing primarily on Asian context, Ernst and Kim (2002) argue that being a part of the global production network (GPN) helps local firms to build capabilities as AMNEs transmit both tacit and explicit knowledge in the process of ensuring that local suppliers meet their specifications. The coordination of value chain activities in different locations essentially require continuous mutual exchange of knowledge, and AMNEs transfer technical and managerial knowledge to the local suppliers. In the industrialization process of East Asian countries, Japan in particular played a significant role in local firms' capability building acting as a knowledge transmitter. As Japanese firms lost comparative advantage in a certain sector, their investment transferred to sunset industries in countries such as Korea and Taiwan in order to facilitate export-led industrialization and produce a dynamic regional division of labor (Hill & Fujita, 1996). In this process, Japanese firms helped local firms to upgrade by providing not only machinery and equipment for the mass-production system in the local region, but also blue prints of products, product specifications, and production and quality control manuals (encoded knowledge). Inviting a number of local engineers, technicians and managers to undergo training in Japan on production and human resource management, thereby transferring embedded and encultured knowledge within these areas, was prevalent to meet the standard of Japanese firms (Hobday, 1995).

Once output capability building is accomplished, latecomer firms often progressively move on to build innovation capability. For less-advanced economies to sustain growth in the process of catch-up, they need to become innovators rather than imitators (Kim, 1997). Even if local firms catch up with output capability, they are challenged in becoming innovators, as firms in less-advanced economies could still have a relatively narrow set of technologies and a limited capacity to generate new indigenous technology on their own (Lall, 1992). As it is well recognized that knowledge recombination based on a broad knowledge base is critical for innovation (Bierly & Chakrabarti, 1996; Rosenkopf & Almeida, 2003), it is of utmost importance for these economies to get access continuously to knowledge residing abroad in order to create innovation (Hannigan, Cano-Kollmann, & Mudambi, 2015). Sourcing knowledge internationally is also beneficial as different countries develop distinctive technological knowledge or competencies by leveraging unique knowledge accumulation patterns (Cantwell, 1989; Phene, Fladmoe-Lindquist, & Marsh, 2006). To sum it up, latecomer economies' connectivity to the global innovation system will be crucial if they want to build innovation capabilities besides catching up with output capabilities.

Contrary to output capabilities, catch-up in innovation capabilities is more challenging for latecomer firms to achieve through participation in GVC and GPN. The aforementioned positive impact of global interaction in the value chain on technological capability building seems to be restricted to upgrading within the area of manufacturing, which is mostly related to output capability. Several studies in the GVC literature found evidence that AMNEs do not facilitate functional upgrading −moving into higher value added activities such as branding, marketing, and innovation− of latecomer firms in their global value chain as this will encroach their business directly (Giuliani et al., 2005; Humphrey & Schmitz. 2002; Lee et al., 2015; Schmitz & Knorringa, 2000). This process of functional upgrading, related to developing innovation capabilities, can be considered as a threat for AMNEs and, therefore, will not be encouraged by leading firms in the value chain, if not directly discouraged (Lee et al., 2015). As Vernon's (1966) product cycle theory predicts, multinational firms tend to keep their new product development close to their headquarters, and even if subparts of product development are outsourced to lower-wage countries, their depth and breadth are nowhere near what occurs at headquarters (Amsden & Chu, 2003). The latecomer firms will then be locked into the position in the value chain, where they keep being engaged in lower value-added activities while increasingly facing price competition from suppliers in other low-income countries. This has been observed in the case of latecomer firms in Latin America (Navas-Aleman, 2011; Szapiro, Vargas, Brito, & Cassiolato, 2016).

Lee et al. (2015) showed that, some Korean small and medium-sized enterprises had to end their relationship with their global buyers and break away from the value chain in order to move from OEM (Original Equipment Manufacturer) to ODM (Original Design Manufacturer) and OBM (Original Brand Manufacturer). As their buyers were against this movement, they had to end the transactions with these buyers and be rather independent in developing new products with their own brand to be sold directly to consumers. They were, however, able to pursue this strategy because they managed to develop certain technological capabilities while they were supplying to AMNEs. This suggests that, while less-developed economies are able to develop output capabilities through global interaction in the value chain, the opportunity for capability building regarding innovation may be restricted in this setting due to power asymmetry and competitive structure. Consequently, these economies may need to rely more on internal knowledge and competences to move on.

4.2.2. Co-inventor network as a channel for global connectivity

When it comes to global connectivity in innovation activities, co-inventor networks can be one of the most effective channels which allow tacit knowledge to be transferred. This is significantly differentiated from other types of international knowledge sourcing mechanisms for two reasons. First, co-inventors usually work on a certain research project for an extensive period of time and maintain contact even after the project is finished, in which mutual trust is developed over time which lays out a favorable environment for tacit knowledge to transfer (Breschi & Lissoni, 2009; Singh, 2005). Second, co-inventors often collaborate with inventors from different countries which have accumulated different types of knowledge over time. Different countries develop distinctive technological competencies by leveraging unique knowledge accumulation patterns (Cantwell, 1989; Pavitt 1987). In a similar vein, Phene, Fladmoe-Lindquist, and Marsh (2006) argue that there are differences in terms of the type of knowledge generated and the manner in which this knowledge is created in different national context. Furthermore, due to the differences in perspectives and cognition, inventors in different national contexts may utilize the same components of knowledge in quite different ways (Phene et al., 2006). Working on a certain research project with inventors from different national contexts, therefore, increases the chance of accessing new tacit knowledge.

4.2.3. Hypothesis development

Based on the discussion in the previous section, we argue that catch-up of latecomer economies through global interaction is likely to happen step-wise. Latecomer firms will be able to learn and build output-related technological capabilities while supplying to AMNEs in the global value chain. Once these firms have accumulated knowledge and reached a certain level of capabilities, they will put more effort into developing innovation capabilities in order to capture higher value, which can be challenging to pursue through the interaction with global buyers due to the risk on the buyer's side of 'nurturing' potential competitors. This process may require that the latecomer firms mostly rely on internally developed knowledge and competences to build innovation capability further, which also implies that the early-stage technological capability building in relation to output capabilities is crucial in forming the basis for further development. Following this logic, we move forward and investigate other underlying mechanisms explaining innovation capability building and global connectivity of Korea and Taiwan. The most relevant factor that seems to coincide with this process of capability building is sectoral catch-up pattern of the two countries.

Based on the observation from technological catch-up in East Asia, some scholars identified different catch-up patterns (Lee & Lim, 2001; Lee, Lim, & Song, 2005; Mu & Lee, 2005). Lee and Lim (2001) categorized three patterns of technological catch-up based on the evolution of selected industries in Korea, which are 'path-following' catch-up, ‘stage-skipping’ catch-up, and ‘path-creating’ catch-up. Firstly, path-following catch-up means that latecomer firms follow the same path taken by the forerunners. Then, stage-skipping catch-up suggests that latecomer firms follow the existing path, but skip certain stages on the way. Lastly, path-creating catch-up happens when the latecomer does not follow the path set by the forerunners and find their own path of technological development. The two last patterns could be considered as ‘leapfrogging’ suggested by Perez and Soete (1988), but they differ from the original notion in a way that the research effort was mostly initiated by private R&D (in collaboration with public R&D) and that it was done in collaboration with foreign companies rather than depending on endogenous generation of knowledge.

In East Asia, it is also observed that the latecomer firms from some countries exercised path-creating catch-up when a new techno paradigm emerged, which allowed them to realize ‘rapid’ economic catch-up by bypassing heavy investments in the previous technology system (Hobday, 1995; Lee, 2005; Lee & Lim, 2001). This pattern is in stark contrast with the conventional view of catch-up in early literature that developing countries catch up with advanced countries by assimilating the old technologies developed from advanced countries (Utterback & Abernathy, 1975; Vernon, 1966). Advantages of utilizing emerging technological opportunities by generating new technologies in the process of catch-up had been emphasized by many scholars (e.g., Freeman & Soete, 1997; Perez & Soete, 1988). Since the market is not developed yet, the entry barrier associated with economy scale does not exist. Further, in the initial stage of a new technological paradigm, the performance of technology is not stable and not parochial to a firm. Thus, entry into emerging technology can be much easier than during the later stage of technological evolution. It also enables latecomer firms to catch up with firms from advanced economies by significantly reducing the lengthy learning process. For these reasons, qualified latecomers advantageously benefit from new opportunities by targeting and specializing in emerging sectors.

The impressive economic catch-up by Korea and Taiwan was possible mainly due to the fact that those countries had entered progressively into newer sectors to identify a new niche in a higher-value segment or industry. Korean and Taiwanese firms made a quick transition from labor-intensive industries to emerging technology-intensive sectors such as telecommunication equipment, memory chips, and digital TVs. Emerging technology-intensive sectors are characterized as having short cycle technologies, indicating that the industry relies less on existing knowledge or technologies and can potentially leverage the greater opportunities that arise from the emergence of new knowledge (Lee, 2013). Within these industries, there may be a less need for latecomer firms to rely on old and established knowledge which is dominated by incumbents, which leads to faster knowledge creation mechanism (Lee, 2013; Park & Lee, 2006). In other words, new knowledge creation in late-comer economies within a new emerging industry may require less connectivity to the global innovation system. Based on this, we hypothesize as follows:

Hypothesis 1: For the latecomer economies exercising path-creating catch-up strategies, the need for co-inventor connectivity is less important as cycle time of technologies shortens.

Business groups, defined as “a gathering of formally independent firms under the single common administrative and financial control of one family” (Chang & Hong, 2000), are the agent of economic expansion in all late-industrializing countries. Although their specific characteristics may vary from economy to economy, the importance of business groups in many emerging economies has been heavily emphasized within the literature. In the context of Korea and Taiwan, the extent to which business groups have played a role in the process of economic development is different, which is mainly attributed to different government policies. The importance of *chaebols*, the Korean business groups, is heavily emphasized within the Korean economy. It is well known that the Korean economic development model is based on a chaebol-led development (Amsden, 1992). Reflecting this, the largest chaebols such as Samsung, Hyundai, and LG account for the majority of Korea's output. In the case of Taiwan, even though it is an economy well known for its small and medium-sized enterprises (Hobday, 1995), large firms were the engines of growth in the early phases of economic development in the early 1970s, accounting for over half of industrial output (Amsden, 1992).

However, due to different government policies, business groups in both countries significantly differ in their size (Gereffi & Wyman, 2014). The Korean government aided capital formation of the large conglomerates and encouraged their lines of business, which enables chaebols to exploit economies of scale as well as scope and generate large surpluses that could be ploughed into internal R&D (Ahn, 2010). The Taiwanese government, in sharp contrast to the Korean government, has adopted a policy to favor new establishments. As a consequence, Taiwanese business groups are relatively small as compared to Korean counterparts (Chung & Mahmood, 2006; Hobday, 1995). As well accepted in the literature, there is a positive correlation between organizational slack and R&D intensity. Larger firms are assumed to have more available resources which can be directed to innovation activities. They would have more resources to buy facilities for R&D, to hire researchers and engineers, and have more time for development activities (Greve, 2003). By contrast, small firms would lack such resources spent on internal R&D, thus a high need for them to rely on external knowledge. By being relatively small in nature, Taiwanese business groups were more likely to rely on external knowledge as compared to Korean business groups.

In addition to their size, these two groups significantly differ in the extent to which they are diversified in their operations. Korean business groups, in general, are highly diversified, having a strong presence in almost every industry (Chang & Choi, 1988). For instance, Samsung group participates in both manufacturing and non-manufacturing industries such as insurance, retailing, and hospitals (Chang & Hong, 2000). In contrasts, Taiwanese business groups dominate in only a selected industries (Hobday, 1995). By operating in almost every sector, Korean business groups are more likely to possess diversified sets of knowledge within their extensive internal networks, which inherently leads to their inclination to depend more on internal knowledge rather than searching for knowledge abroad. In a similar vein, by operating in a very limited number of industries, Taiwanese business groups are more likely to have limited access to diverse knowledge, which leads them to rely more on external knowledge sourcing. Based on this, we hypothesize as follows:

Hypothesis 2: As compared to Korean business groups, Taiwanese business groups are more likely to have higher degree of co-inventor connectivity.

4.3. Methnology and Empirical Analaysis

4.3.1. Research Setting: The Electronics Industry

The electronics industry is an exceptional target for studying innovation capability catch-up in East Asia. It has been recognized as one of the most competitive industries where less developed economies have little chance of succeeding in catch-up due to the nature of this industry as being technologically complex (Hobday, 1995). Traditionally, the development of the electronics industry in East Asia was initiated mainly due to a massive expansion of international production by foreign electronics firms, from both Japan and other major advanced countries such as the U.S., combined with strong government support through industrial policy (Belderbos & Zou, 2006; Ernst & Guerrieri, 1998). Many firms in the electronics industry in East Asia successfully transformed themselves from imitators or mere suppliers for their foreign buyers to innovators in the past three decades. To reflect this, East Asian countries have become a home to Fortune 500 global companies such as Samsung Electronics (Korea), Hon Hai Precision Industry (also known as Foxconn Technology Group (Taiwan), Quanta Computer (Taiwan), Huawei (China) (albeit it came into the spotlight much later than firms from Korea and Taiwan), and so on. Indeed, by the late 1980s, electronics became the largest industrial sector for both Korea and Taiwan (Hobday, 1995). Patent data from USPTO reinforces this: industrial structure of Korea and Taiwan shows that the electronics industry has been a major sector in these economies (see Figure 1). As a home for global companies such as Sony and Hitachi, Japan also shows a similar pattern (see Figure 2).

4.3.2. Data and Method

Our main data comes from Harvard Patent Network Dataverse (DVN), a product of the Harvard Business School and the Harvard Institute of Quantitative Social Science, which provides inventor-level patent data from US Patent and Trademark Office (USPTO) during the period of 1975-2010[2] (Li, Lai, D'Amour, Doolin, Sun, Torvik, Amy, & Fleming, 2014). As the data was originally constructed to study inventor mobility and networks, it is aggregated at the individual inventor level with inventor name and location (including GPS coordinates, street address, city, and country). It also contains other information on patents available from USPTO patent document such as patent number, technology class, application year, grant year, abstract, cited work, assignee name, and assignee location (including city and country). While this publicly available data alleviates the challenges involved in the collection of patent data which is well documented in the literature, we complement this data with firm- and country-level data from other publicly available sources.

Despite of some criticism, patents are known to represent firms' inventive activity, and thus, are frequently used for the analysis of the process of technological change (e.g., Awate et al., 2012; Cantwell & Zhang, 2013; Griliches, 1998). Since the electronics industry is a high-technology industry with active patenting activities (Penner-Hahn & Shaver, 2005), patent-related measures would provide strong insights into innovation activities in this industry. We extracted electronics patents using the technology classification suggested by Hall, Jaffe, and Trajtenberg (2001). With this dataset, we identify patents that are connected to Korea and Taiwan. For the comparison

[2] Due to the truncation problem (Hall et al., 2001), interpretation the data after 2005 should be with care.

purpose, we also identify patents that are connected to Japan. As the first Asian economy to industrialize, Japan was more advanced, especially during the industrialization period of Asian countries (Amsden & Chu, 2003; Hsiao & Hsiao, 1996). Hence, we expect that it would present a different case from Korea and Taiwan.[3] We do this by identifying the patents that have at least one inventor located in the specific country. As a result, observation of our data consists of 27,220, 17,093, and 113,340 patents for Korea, Taiwan, and Japan respectively. Our study period is from 1980 to 2010.

4.3.3. Dependent Variable

Following Hannigan, Cano-Kollmann, and Mudambi (2015), we construct a measure called *Co-inventor connectivity*. It is calculated as $1 - \sum_{i=1}^{N} s_i^2$ where s_i is the share of inventors located in country i and N is the number of inventor countries that appear in a patent. Conceptually this measure is similar to the Herfindahl index, taking a value between 0 and 1, but contrary to Herfindal index, it measures how dispersed the inventors are across countries. The inventors on a focal patent are more dispersed as the index increases asymptotically toward 1.

4.3.4. Independent variable

There are two independent variables used in this study. First, *Cycle time of technologies*. Following Jaffe and Trajtenberg (2002), we calculate *cycle time of technologies* as the time difference between the grant year of the citing patent and that of the cited patents. To construct this variable, we combined our main data with data from

[3] China is in a different developmental stage compared to Korea and Taiwan (Hobday, 1995; Holtz, 2008) as it has been included in the international division of labor within East Asia since the 1990s (Baek, 2005). Although it was included in our discussion on descriptive results as a reference point, it was excluded in our main analysis.

National Bureau of Economic Research (NBER). *Cycle time of technologies* was partially available from NBER which provide us with data from 1980 to 1999. From the period of 2000 to 2010, this was calculated with our main data. Using application year is prevalent when it comes to patent data, however, since the citation data from Harvard Patent Network Dataverse (DVN) does not provide us with application year, we computed this variable by grant year of the citing patent and that of the cited patents. It was calculated at each patent level. Second,*Business group.* For Korea, we created *Chaebol,* a dummy variable that takes 1 if the firm is a part of a Korean business group. Similarly, for Taiwan, we created *Jituanquiye,* a dummy variable that takes 1 if the firm is a part of a Taiwanese business group. Finally, for Japan, *keiretsu*, a dummy variable was created.

4.3.5. Control variables

We include three different levels of control variables that could possibly influence the relationship between cycle time of technologies and co-inventor connectivity, and therefore could confound our results.

First, we include country-level control variables which were obtained from *the World Bank Development Indicators*. *School enrollment in tertiary education* was measured by the total enrollment in tertiary education as a percentage of the total population. *Air transportation* was measured by registered carrier departures worldwide including both domestic and international takeoffs. While relatively neglected compared to trade in the literature, air transportation reflects to the extent to which a country is connected to the rest of the world (Arvis & Shepherd, 2011). *Merchandise trade* was measured by a share of GDP is the sum of merchandise exports and imports divided by the value of GDP, all in current U.S. dollars. In economics in particular, data on export and import has been frequently used as the most basic measure for a country's openness to the world (e.g. Dar & Amirkhalkhali, 2003; Gries, Kraft, & Meierrieks, 2009; Yanikkaya, 2003).

Second, we include firm-level control variables. *Foreign MNE* is a dummy variable that takes 1 if the firm is international. Foreign MNEs, especially from advanced economies such as US and Europe, are usually big in size, thus more connected across locations through their subsidiaries and alliance partners. *Other organization* is a dummy variable that takes 1 if the organization that is not a business firm such as universities and research institutions. *Leader* is a dummy variable that takes 1 if firms are in the upper quartile of the sample in terms of their patent pool.

Third, we include patent-level control variables such as *Number of inventors* and *Number of assignees*.

Finally, country dummy and year dummy variable are included in the model.

4.3.6. Model and Econometric Approach

The basic regression model used in the analysis is as follows:

$$\begin{aligned}\mathrm{Co-inventor\ connectivity} &= logit^{-1}(\beta_0 + \beta_1\,\mathrm{Cycle\ time\ of\ technologies} + \beta_2\,\mathrm{Business\ group} \\ &+\ country-level\ controls + firm-level\ controls + patent \\ &- level\ controls + country\ dummy + year\ dummy) + \varepsilon_{ijt}\end{aligned}$$

The model above is estimated using Generalized Linear Model (GLM) regressions. As our dependent variable takes a form of fraction between 0 and 1 (including both extremes), one option for the regression analysis could be to log-transform the variable and run a linear regression. However, a large share of our dependent variable has the value 0, and therefore log transformation in our case will lead to a lot of missing values. Another option is to treat the variable as censored variable and run a tobit regression, but this can be problematic as our variable is not really censored (Baum, 2008). The values outside the [0,1] interval are not feasible for our dependent variable from the way it is calculated. Therefore, we adopt a strategy suggested by Papke and Wooldridge (1996) and run a GLM regression using logit link function and the binominal distribution, which allows handling both 0s and 1s as well as the intermediate values.

4.4. Empirical Results

4.4.1. Descriptive results

We begin by exploring co-inventor connectivity for the countries in our sample. The country dispersion index of the Korean, Taiwanese, Japanese, and Chinese patents in the electronics industry is provided in Tables 1. As seen, we observe that the lowest level of co-inventor connectivity in Japanese patents throughout all the years followed by Korean patents. Taiwanese patents seem to show higher level of connectivity index. However, if we compare that with that of Chinese patents, the values for Taiwanese patents are still quite low. T-Tests for the two groups (both Korea, Taiwan, and Japan vs. China and Korea and Taiwan vs. China) show that there is significant difference between two groups, confirming that compared to Chinese patents, there is a low level of inter-country collaboration in the electronics industry in Korea and Taiwan.

The low connectivity level over time in Korea and Taiwan is rather unexpected. As Korea and Taiwan have developed their technological capabilities tremendously since the 1970s and 80s, one would expect an increasing trend of inventor connectivity across countries, which can reflect an increasing effort to source advanced knowledge in other countries to enhance competitiveness. This gets more interesting if we look at the corresponding values for Chinese patents. Not only is the absolute value for the connectivity high throughout all years, but also shows the increasing pattern over time, which indicates that China is rapidly catching-up with advanced economies actively engaging in inter-country collaboration to draw on advanced knowledge residing in other countries.

4.4.2. Regression Results

The summary statistics and Pearson correlations for the full sample are reported in Table 2. None of the correlations are high enough to warrant any concern about multicollinearity.

The results from Generalized Linear Model (GLM) regressions are presented in Table 3. We employed a multiple regression approach to test our hypothesis. Results from our baseline model (Model 1) indicates that consistent with intuition, there is statistically positive relationship between the volume merchant trade and co-inventor connectivity, while negative relationship between school enrollment in tertiary education and co-inventor connectivity. Negative relationship between school enrollment in tertiary education and co-inventor connectivityis quite surprising given that well-educated population is more likely to be open to the innovation network worldwide. Results from model 2 shows that as consistent with intuition, foreign MNEs are more likely to be involved in international knowledge sourcing through co-inventor networks. This is expected since compared to local firms, foreign MNEs have more resources and networks, thus more likely to be engage in international innovation collaboration. Leader firms are more likely to be closed. Results from model 3 shows that there is positive relationship between number of inventors and assignees in a focal patent and co-inventor connectivity. Then model 4 confirms our hypothesis 1 that there is statistically positive relationship between the cycle time of technologies and co-inventor connectivity. This means that if knowledge or technology is well-established, then one needs to rely on drawing and learning such knowledge from other advanced economies. Conversely, if knowledge or technology is new and emerging, then one can cut the lengthy learning process since there is less need to study old knowledge. Also, the result shows that there is different between Korean business group (known as *Chaebol*) and Taiwanese business group (*Jituanquiye*) when it comes to openness. Namely, Korean business groups do not tend to engage in international innovation collaboration, while Taiwanese business groups are quite opposite, drawing knowledge from other countries, confirming hypothesis 2.

Then, we ran the same regression for a sub-sample-i.e. Korea and Taiwan, and Japan and the results are provided in Table 4. As seen in Table 4, there is statistically positive relationship between the cycle time of technologies and co-inventor connectivity, confirming hypothesis 1. Table 5 also shows that in the case of Taiwan, there is statistically positive relationship between the cycle time of technologies and co-inventor connectivity. The main effect seems to be a bit stronger in the case of Korea (coefficient of cycle time of technologies is 0.0181 and 0.0121 for Korea and Taiwan respectively) and this main effect is not statistically significant in the case of Japan. In addition, as seen before, we found that there is different between Korean business group (*Chaebol*) and Taiwanese business group (*Jituanquiye*) when it comes to international innovation collaboration. Similar to Korea, Japanese business groups (*Keiretsu*) are negatively correlated to co-inventor connectivity.

For East Asian countries such as Korea and Taiwan, the industrialization process took place mainly during the 1980s and 1990s (Moreira, 1995). Therefore, to see if there is a difference depending on the time frame, we further conducted analysis after 2000 and the results are provided in Table 5. The results are quite similar to what we observed from Table 3 (for the full sample period) except for the increase in coefficient in cycle time of technologies by 55%[4]. Same as before, we ran the same regression for sub-sample-i.e. Korea, Taiwan, and Japan, and the results are provided in Table 6. What we found from the Table 6 is that the main effect is no longer significant in the case of Korea, while it is still positive and significant in the case of Taiwan. In the case of Japan, it is still not statistically significant. Same as seen from the Table 5, Korean business groups and Taiwanese business groups differ from each other. That is, Korean business groups are less likely to be connected, while Taiwanese business groups are more likely to be connected to the world. Similar to Korea, Japanese business groups are substantially closed to the global innovation system.

To control the robustness of our results, we ran another regression. In this model, we replaced the cycle time of technologies which was measured by the average time difference between the grant year of the citing patent and that of the cited patents with the maximum time difference between the grant year of the citing patent and that of the cited patents. The results are provided in Table 7. One thing noticeable is that the main effect is still significant and positive although the coefficient has decreased. In addition, since the

[4] With a relatively low coefficient, this indicates that there is 0.8% increase in the odds of having a high dispersion with one unit increase in the cycle time of technology.

patents produced by Samsung and LG, two biggest chaebol in Korea, are almost 70%, we replaced chaebol dummy with Samsung & LG dummy.

4.5. Discussion and Conclusion

This paper sheds light on innovation catch-up in Korea and Taiwan. We began this paper by noting that connectivity to the global innovation system through co-inventorship or innovation collaboration has been recognized as an important conduit for innovation catch-up. Especially in the case of less-developed countries which are eager to catch-up with advanced economies, connectivity becomes much more critical, and empirical evidence in the current literature seems to support that. Contrary to the existing literature, our results present a quite different story. As seen previously, in the case of Korea and Taiwan, by focusing on emerging technologies (which has a short cycle time in nature), they could develop new technologies based on indigenous knowledge without depending heavily on foreign knowledge, which could have led to limited connectivity to the global innovation system.

This finding makes sense if we think about the industrialization process which took place in the 1980s and 1990s. As latecomer countries, Korea and Taiwan needed to catch-up with advanced economies as quickly as possible by shortening the lengthy learning process. It is reasonable to assume that focusing on areas in which firms from advanced economies had dominated would give latecomers a huge disadvantage to compete with incumbents in the market (Amsden & Chu, 2003). What they had to do as resource-poor latecomer countries in the market was to explore technological niche areas instead of focusing on learning old and established knowledge, which means that these countries had a lesser need to rely on drawing knowledge from outside. Existing literature points out that the resources for innovation of latecomers such as Korea and Taiwan are somewhat limited and concentrated in certain sectors, whereas the drivers of innovation among technologically advanced economies are broad-ranging (Furman, Porter, & Stern, 2002; Hu & Mathews, 2005). Japan, as a technologically advanced economy, led the way in terms of technology by pursuing diverse developments in a wide range of technology fields in the electronics industry (Amsden & Chu, 2003). The technological portfolio in these three countries confirms this: the Herfindahl Index [5]which has also been used to measure countries' specialization in manufacturing (e.g., Weinhold & Rauch, 1997) indicates that Taiwan (0.2544) is highly specialized in knowledge creation, followed by Korea (0.1138) and Japan (0.0498).

Our result from a sub-sample analysis during the period 2000 to 2010 provides us with a further interesting story. As it was with the full sample period 1980 to 2010, cycle time of technologies does seem to have an effect. What we noticed, however, is that the main effect no longer holds in the case of Korea, while it is still positive and significant in the case of Taiwan. Observing this, one can speculate that there was transition in terms of technology strategy in these countries. As stated previously, the industrialization process of East Asian countries aggressively took place mainly during the 1980s and 1990s. In the Korean case, as it rapidly caught up with advanced economies, Korean firms might expand their technology portfolios to improve their technological positions On the contrary, Taiwan seems to still focus on small areas of technology in the electronics industry. Interestingly, we found a stark difference among business groups in

[5] This is calculated as $H = \sum_i s_i^2$ where $s_i$is the country's share of patents in the ^{i}th patent class within the electronics industry.

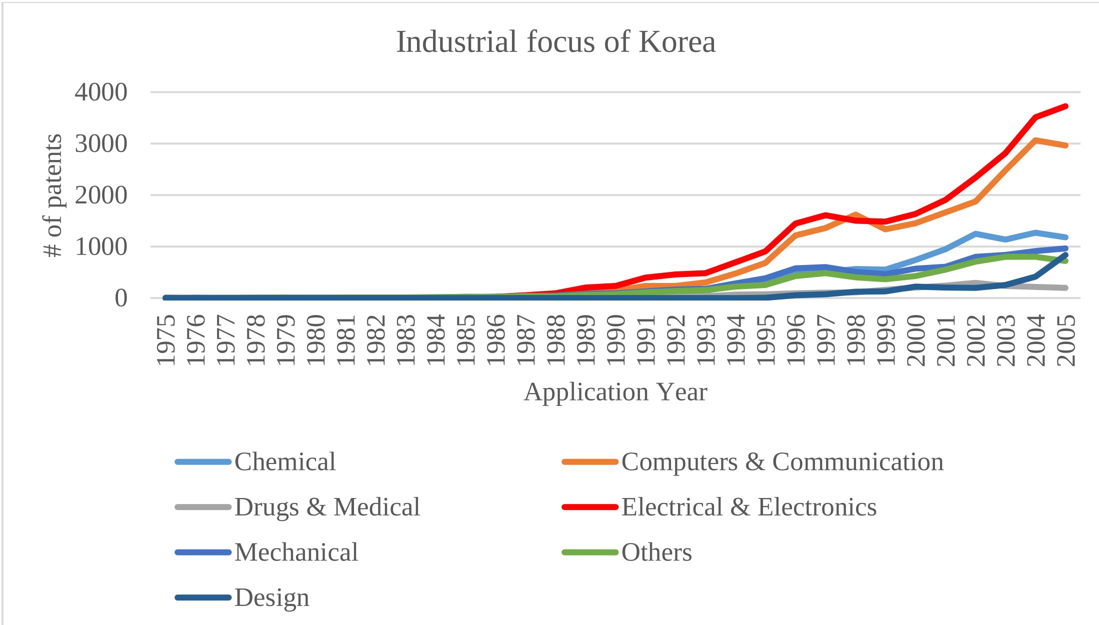
these countries. Throughout the analyses, we found that Korean and Japanese business groups are quite closed, while Taiwanese business groups are more open to the global innovation system. One explanation could be the different institutional background behind the economic development in Korea and Taiwan. The Korean development is largely led by family-owned mega businesses called chaebol, which received dedicated support from the Korean government over a long period of time. On the other hand, the Taiwanese government encouraged new establishments, which led to more SME-network oriented development (Amsden, 1992). This could explain the difference in size in the business groups in these countries. Korean business groups are on average larger, whereas Taiwanese business groups are more numerous and much smaller (Chang, 2003, Chang, Chung, & Mahmood, 2006). In addition, Taiwanese groups are less vertically-integrated compared to Korean business groups (Feenstra, Yang, & Hamilton, 1999). Due to its smaller size and more focused business areas, the Taiwanese firms could have had more motivation to source knowledge from outside in their innovation activities. Another explanation could be the corporate cultural difference among these countries. Japan is traditionally well known for its rigid corporate culture which is largely responsible for preventing its firms from integrating into the world economy by not letting them embrace new ideas and new people (*The Economist*, 2010). Additionally, Japanese firms' desire to protect their intellectual property is very high, preventing them from engaged in alliances with foreign partners (*The Economist*, 2010). Rather, Japanese firms have strengthened the protection of their intellectual property through inter-*keiretsu* collaborations (Hu, 2012). A similar phenomenon is also observed in Korean firms. Chang (2008) pointed out that one of the obstacles that Samsung Electronics needs to overcome to be truly a global company is embracing new ideas by hiring new people regardless of nationality. Unlike Korean and Japanese counterparts, among other well accepted features, the ethnic Chinese are known for the tendency towards entrepreneurship (Fong & Luk, 2006; Hobday, 1995).

Although our results seem to explain why Korea and Taiwan are relatively not connected to the global innovation system, it may be possible that international knowledge sourcing could occur not through co-inventor networks, but through other forms of knowledge transfer mechanism, therefore our results might need to be interpreted with care. There are different mechanisms of international technology transfer that will not be detected in our connectivity measure. While FDI, international research collaboration, and participating in global value chain are typical transfer mechanisms that encourage more geographically dispersed innovation activities, technologies can also be transferred through movement of goods in international trade and movement of people in relation to work, study, and migration, which do not require direct international connection. There is evidence that leading Korean firms acquire technology through people who were educated and trained in advanced economies, mostly in the U.S. and Japan. For instance, the first president of the Samsung Advanced Institute of Technology (SAIT) was an ex-employee of a leading US firm. In 1992, there were at least 60 foreign engineers working with researchers and engineers at Samsung (Hobdaty, 1995). In a similar vein, licensing could have been another mechanism through which local firms source knowledge and this would not be reflected in our global connectivity measure.

The catch-up process of Korea and Taiwan shows us that connectivity through co-inventor networks is not the only one route to successful innovation capability building.

Rather, it shows us that there are other routes to successful catch-up. As seen among others, focusing on emerging technologies can be one of the catch-up strategies for emerging economies to adopt. However, this has to be interpreted with caution in the sense that for this strategy to work, fundamentals have to be secured first. Both countries, in fact, are well known to be huge investors in the education system which is an essential ingredient for industrial development during the early years of industrialization (Guo, 2005; Sullivan, 1998), and that might be the main reason why they have succeed in innovation catch-up without relying on external knowledge significantly. Reflecting this, statistics show that since the 1980s, the both government expenditure on education accounted for about 5 % of GDP (Mai & Shi, 2001; UNESCO, 2015).

Figure 4.1: Industrial structure of Korea and Taiwan (1975-2005)



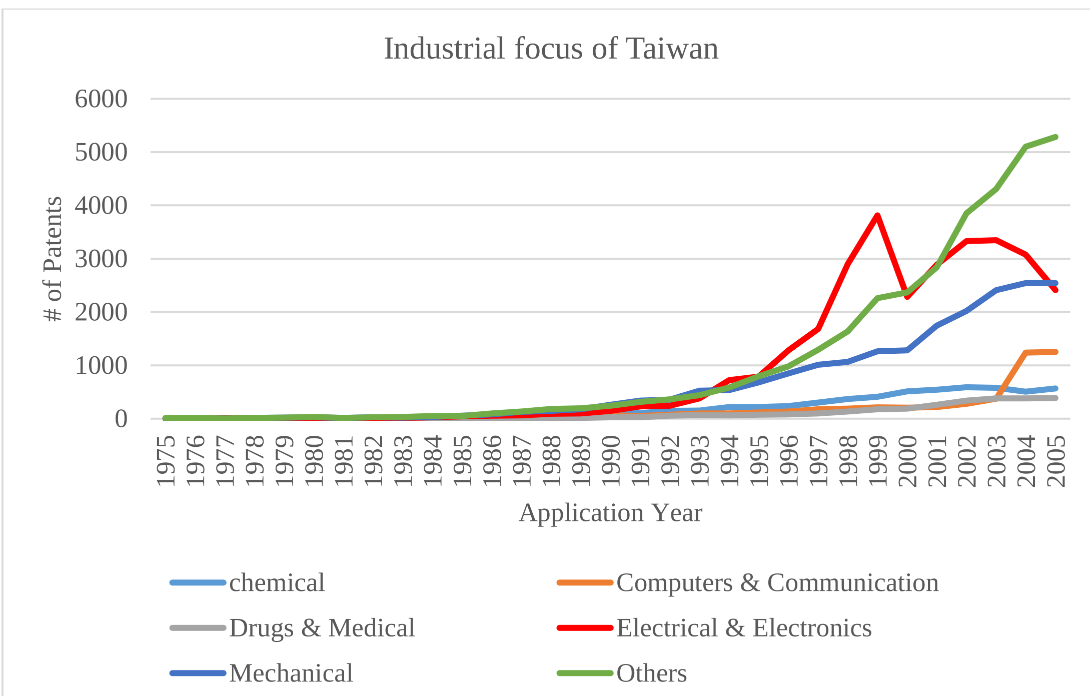


Figure 4.2: Industrial structure of Japan (1975-2005)

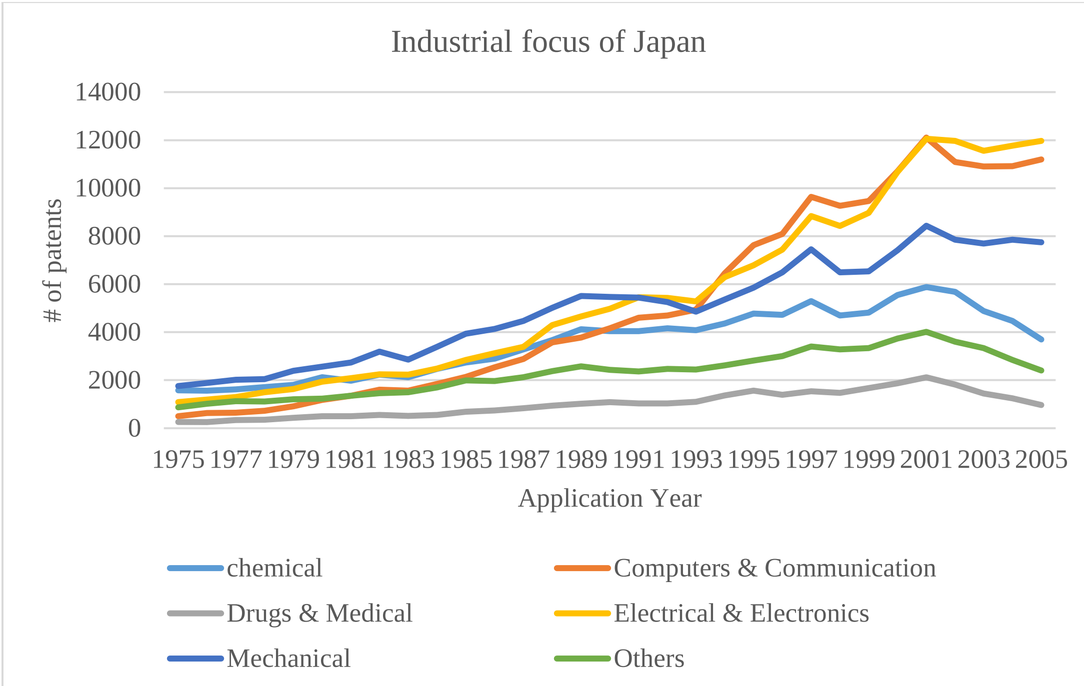


Table 4.1: Co-inventor connectivity in electronics industry

	Korea		**Taiwan**		**Japan**	
Year	Observations	Mean	Observations	Mean	Observations	Mean
1980-1989	182	0.045	267	0.023	24661	0.0029
1990-1999	6332	0.009	4045	0.016	58915	0.0064
2000-2009	20196	0.010	11125	0.030	92091	0.0081
2010	33	0.013	32	0.027	69	0.0046
Total	26743	0.019	15469	0.024	175736	0.0055

Table 4.2: Summary statistics and Pearson correlation

Variable	Mean	s.d.	1	2	3	4	5	6	7	8
1. Co-inventor connecitivity	0.0164	0.0855	1.00							
2. Cycle time of technologies	7.3435	6.0397	0.0129***	1.00						
3. School enrollment in tertiary education	75.3703	19.0789	-0.0161***	-0.1079***	1.00					
4. Merchandise trade	71.2145	20.0412	0.1091***	0.0413***	-0.0131***	1.00				
5. Air transportation	336598.5	163873.8	0.0541***	-0.0297***	-0.3806***	0.6723***	1.00			
6. Foreign MNE	0.0207	0.1424	0.2855***	0.0023	0.0054	0.0370***	0.0376***	1.00		
7. Other organization	0.0543	0.2266	0.0336***	0.0008	-0.0227***	0.0085***	0.0058***	-0.0295***	1.00	
8. Leader	0.3246	0.4682	-0.1064***	-0.0617***	0.2772***	-0.4453***	-0.4859***	-0.0947***	-0.1662***	1.00
Variable	**Mean**	**s.d.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
9. Chaebol (Korean business group)	0.5297	0.4991	-0.1622***	-0.0856***	0.3742***	-0.6884***	-0.7497***	-0.1452***	-0.2544***	0.6527***
10. Jituanquiye (Taiwanese business group)	0.1353	0.3421	0.0904***	-0.1297***	-0.2390***	0.3834***	0.5140***	-0.0273***	-0.0948***	-0.2743***
11. Number of inventors	2.2332	1.6194	0.1463***	-0.0606***	0.2313***	-0.0071	-0.0794***	0.0730***	0.1766***	0.1376***
12. Number of assignees	0.9301	0.3240	0.0864***	-0.2803***	0.2355***	-0.1333***	-0.1947***	0.0816***	0.0977***	0.1551***

Table 4.2, continued

Variable	Mean	s.d.	9	10	11	12
9. Chaebol	0.5297	0.4991	1.00			
10. Jituanquiye (Taiwanese business group)	0.1353	0.3421	-0.4200***	1.00		
11. Number of inventors	2.2332	1.6194	0.0286***	0.0153***	1.00	
12. Number of assignees	0.9301	0.3240	0.2425***	0.0980***	0.2083***	1.00

Table 4.3: Regression Results: Full sample (Korea and Taiwan) (1980-2010)

	Full sample					
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*
Main effect						
Cycle time of technologies				0.0115***		0.0137***
				[2.95]		[3.87]
Chaebol					-2.0549***	-2.0819***
					[-14.32]	[-13.92]
Jituanquiye					0.7170***	0.7562***
					[9.85]	[10.12]
Controls						
Tertiary enrollment	-0.061***			-0.0635***	-0.0502***	-0.0579***
	[-5.35]			[-5.45]	[-4.41]	[-4.97]
Merchant trade	.0.014***			0.0066	0. 0110**	0.0123**
	[3.56]			[1.59]	[2.73]	[2.93]
Air transportation	-3.20e-07			-1.77e-06***	-2.66e-06***	-2.57e-06***
	[-0.57]			[-3.08]	[-4.61]	[-4.40]
Foreign MNE		2.367***		2.3143***	2.0404***	2.0271***
		[30.35]		[33.43]	[25.06]	[24.43]
Other organization		0.2335**		-0.1162	-0. 3296**	-0.2901**
		[2.40]		[-2.65]	[-3.38]	[-2.65]
Leader		-0.0887**		-1.5247*	-0. 2572+	-0.2513
		[2.40]		[-1.63]	[-1.73]	[-1.63]
Inventor number			0.3058***	0. 2877***	0. 2637***	0.2625***
			[31.92]	[25.50]	[23.10]	[22.43]
Assignee number			0.9699***	0. 6307***	0. 6356***	0.6427***
			[6.89]	[5.59]	[6.25]	[6.06]
Country Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	44,293	44,293	44,293	44,293	44,293	44,293
Log pseudolikelihood	-3319.05	-3200.38	-3108.76	-2715.90	-2707.34	-2612.75

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

Table 4.4: Regression Results: Sub-sample (1980-2010)

	Korea				Taiwan		
	(1)	(2)	(3)		(1)	(2)	(3)
VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*	VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*
Main effect				*Main effect*			
Cycle time of technologies		0.0308***	0.0181**	*Cycle time of technologies*		0.0047***	0.0121***
		[3.02]	[2.43]			[1.06]	[2.80]
Chaebol	-2.2351***		-2.2616***	*Jituanquiye*	0.7355***		0.7580***
	[-14.20]		[-13.62]		[9.53]		[17.04]
Controls				*Controls*			
Foreign MNE	2.0155***	3.2211***	2.0339***	Foreign MNE	2.0899***	1.6971***	2.0519***
	[16.79]	[16.88]	[16.24]		[19.08]	[15.97]	[18.24]
Other_org	-0.3523**	-0.9558**	-0.2742+	Other_org	-0.3714**	-0.7597**	-0.3665*
	[-2.52]	[-2.30]	[-1.91]		[-2.11]	[-4.21]	[-1.96]
Leader	-0.0138	-1.0840***	-0.0793	Leader	-0.7464	-0.7630	-0.7099
	[-14.20]	[-8.66]	[-0.49]		[-1.15]	[-1.24]	[-1.10]
Inventor_num	0.2603***	0. 2664***	0.2471***	Inventor_num	0.2662***	0.2923***	0.2729***
	[15.13]	[15.61]	[13.88]		[17.05]	[18.36]	[17.04]
Assignee_num	0.6598***	0.5463***	0.6536***	Assignee_num	0.6226***	0.6701***	0.6305***
	[5.48]	[3.31]	[5.28]		[4.54]	[4.43]	[4.36]
Year Dummies	*Yes*	*Yes*	*Yes*	*Year Dummies*	*Yes*	*Yes*	*Yes*
Observations	27,220	27,220	27,220	Observations	17,093	17,093	17,093
Log pseudolikelihood	-1047.99	-1047.82	-995.16	Log pseudolikelihood	-1641.17	-1622.78	-1599.53

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

Table 4.4, continued

	Japan		
	(1)	(2)	(3)
VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*
Main effect			
Cycle time of technologies		0.0058	0.0046
		[1.35]	[1.80]
Keiretsu	-0.6088***		-0.6140***
	[-10.45]		[-9.11]
Controls			
Foreign MNE	3.1243***	3.3668***	3.1013***
	[57.66]	[49.63]	[49.63]
Other_org	1.6226**	2.0311***	1.7382***
	[10.89]	[12.94]	[10.97]
Leader	-0.2975***	-0.4405***	-0.2747***
	[-3.73]	[-4.82]	[-2.97]
Inventor_num	0.2254***	0.2041***	0.2129***
	[28.58]	[24.14]	[24.50]
Assignee_num	0.4294***	0.4476***	0.4650***
	[13.23]	[11.23]	[11.93]
Year Dummies	*Yes*	*Yes*	*Yes*
Observations	113,340	113,340	113,340
Log pseudolikelihood	-3739.34	-2834.36	-2814.80

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

Table 4.5: Regression Results: Full sample (Korea and Taiwan) (2000-2010)

VARIABLES	(1) DV: *Connectivity*	(2) DV: *Connectivity*	(3) DV: *Connectivity*	(4) DV: *Connectivity*	(5) DV: *Connectivity*	(6) DV: *Connectivity*
Main effect						
Cycle time of technologies				0.0186*** [3.17]		0.0213*** [5.32]
Chaebol					-2.0549*** [-14.32]	-1.6038*** [-10.31]
Jituanquiye					0.7170*** [9.85]	1.1036*** [12.35]
Controls						
Tertiary enrollment	-0.015 [-0.66]			-0.0109 [-5.45]	-0.0502*** [-4.41]	-0.0080 [-0.33]
Merchant trade	.0.013*** [3.01]			0.0039 [0.90]	0. 0110** [2.73]	0.0098* [2.25]
Air transportation	-2.99e-06* [-2.01]			-4.78e-06*** [-3.14]	-4.66e-06*** [-4.61]	-4.41e-06*** [-2.89]
Foreign MNE		2.5418*** [26.21]		2.3229*** [30.32]	2.0404*** [25.06]	2.2299*** [22.95]
Other organization		0.3418*** [2.67]		- [-2.65]	-0. 3296** [-3.38]	-0.1685 [-1.32]
Leader		-0.3782* [-2.26]		-1.5247* [-1.63]	-0. 2572+ [-1.73]	-0.6258*** [-3.78]
Inventor number			0.2723*** [26.33]	0. 2877*** [25.50]	0. 2637*** [23.10]	0.2277*** [17.99]
Assignee number			0.9509*** [21.67]	0. 6307*** [5.59]	0. 6356*** [6.25]	0.7016*** [5.53]
Country Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	31,902	31,902	31,902	31,902	31,902	31,902
Log pseudolikelihood	-2490.09	-2340.62	-2122.40	-2715.90	-2707.34	-2002.69

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

Table 4.6: Regression Results: Sub-sample (2000-2010)

	Korea				Taiwan		
	(1)	(2)	(3)		(1)	(2)	(3)
VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*	VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV *Connectivity*
Main effect				*Main effect*			
Cycle time of technologies		0.0216	0.0125	*Cycle time of technologies*		0.0184***	0.0211***
		[1.91]	[1.28]			[2.64]	[4.80]
Chaebol	-1.7741***		-1.7502***	*Jituanquiye*	0.9850***		1.0349***
	[-10.28]		[-9.99]		[11.45]		[11.87]
Controls				*Controls*			
Foreign MNE	2.1473***	3.1215***	2.1702***	Foreign MNE	2.2642***	1.6762***	2.2712***
	[15.10]	[26.19]	[15.01]		[18.05]	[14.24]	[18.04]
Other_org	-0.0791	-0.8684	-0.1743	Other_org	-0.4145+	-1.0533***	-0.3680*
	[-1.06]	[-1.56]	[-1.02]		[-1.96]	[-4.59]	[-1.70]
Leader	-0.5055***	-1.3270***	-0.5124***	Leader	-0.8222	-0.7256	-0.7666
	[-2.88]	[-8.78]	[-2.92]		[-1.20]	[-1.12]	[-1.13]
Inventor_num	0.2364***	0.2359***	0.2321***	Inventor_num	0.2208***	0.2587***	0.2251***
	[12.40]	[12.33]	[12.11]		[13.27]	[14.31]	[13.31]
Assignee_num	0.8254***	0.7989***	0.8461***	Assignee_num	0.6269***	0.6561***	0.6387***
	[5.84]	[4.23]	[6.05]		[4.06]	[3.82]	[4.19]
Year Dummies	*Yes*	*Yes*	*Yes*	*Year Dummies*	*Yes*	*Yes*	*Yes*
Observations	20,338	20,338	20,338	Observations	11,564	11,564	11,564
Log pseudolikelihood	-763.92	-758.28	-741.95	Log pseudolikelihood	-1245.0	-1236.83	-1233.02

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

Table 4.6, continued

	Japan		
	(1)	(2)	(3)
VARIABLES	DV: *Connectivity*	DV: *Connectivity*	DV: *Connectivity*
Main effect			
Cycle time of technologies		0.0087	-0.0105
		[1.88]	[-1.54]
Keiretsu			-0.5825***
	-0.5786***		[-9.14]
Controls	[-9.07]		
Foreign MNE	3.0812***	3.2931***	3.0730***
	[52.44]	[53.45]	[52.27]
Other_org	1.4938***	1.8992***	1.5030***
	[8.53]	[10.12]	[8.57]
Leader	-0.3671***	-0.5117***	-0.3706***
	[-4.02]	[-4.71]	[-4.06]
Inventor_num	0.2572***	0.2405***	0.2585***
	[27.85]	[22.56]	[28.20]
Assignee_num	0.3995***	0.4145***	0.3976***
	[12.03]	[10.04]	[11.93]
Year Dummies	*Yes*	*Yes*	*Yes*
Observations	92,319	92,319	92,319
Log pseudolikelihood	-3098.28	-2300.21	-2197.25

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

Table 4.7: Regression Results: Full sample (Korea and Taiwan)

	Full sample			
VARIABLES	(1) DV: *Connectivity*	(2) DV: *Connectivity*	(3) DV: *Connectivity*	(4) DV: *Connectivity*
Main effect				
Cycle time of technologies (max value)				0.0089*** [5.78]
Chaebol				-1.5971-*** [-10.27]
Jituanquiye				1.0098*** [12.36]
Controls				
Tertiary_enroll	-0.0157 [-0.66]			-0.0054 [-0.22]
Merchant_trade	.0.0130*** [3.01]			0.0098* [2.26]
Air_trans	-2.99e-06* [-2.01]			-4.55e-06*** [-2.97]
Foreign MNE		2.5418*** [26.21]		2.1999*** [22.63]
Other_org		0.3418*** [2.67]		-0.1529 [-1.20]
Leader		-0.3782* [-2.26]		-0.6258*** [-3.78]
Inventor_num			0.2723*** [26.33]	0.2268*** [17.94]
Assignee_num			0.9509*** [21.67]	0.7021*** [5.55]
Country Dummies	*Yes*	*Yes*	*Yes*	*Yes*
Year Dummies	*Yes*	*Yes*	*Yes*	*Yes*
Observations	44,293	44,293	44,293	44,293
Log pseudolikelihood	-2490.09	-2340.62	-2122.40	-2001.28

*** p<0.01, ** p<0.05, * p<0.1, † p < .10

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