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Catch-up and connectivity to global innovation systems: A limited flying geese model?

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Abstract

Connectivity to global innovation systems has been known to be crucial for maintaining competitiveness in the global market. In the context of catching-up, it also provides opportunities for closing the technological gap between advanced and emerging economies. It is therefore expected that increasing connections to global innovation systems accelerates catch-up processes in recently emergent countries. Such connectivity has been demonstrated as a mechanism for catch-up in many national contexts. However, Korea, our empirical context, shows quite different innovation trajectory. Utilizing the patent data from US Patent and Trademark Office (USPTO), we compare the country dispersion of inventors in the electronics and pharmaceutical industry in Korea, Denmark, and Japan to illustrate how globally connected Korea is in terms of new knowledge creation. Our analysis reveals that unlike Denmark, Korea is surprisingly closed to the world when it comes to creation of new knowledge. Its trajectory is similar to that of Japan. Korea?s similarity with Japan and its dissimilarity with Denmark in terms of connectivity to global innovation systems at the patent level, suggests that the development of innovation trajectory as well as the general industrialization process of Korea conforms to some extent to the ?flying geese model? developed by Kojima.

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ABSTRACT

Connectivity to global innovation systems has been known to be crucial for maintaining competitiveness in the global market. In the context of catching-up, it also provides opportunities for closing the technological gap between advanced and emerging economies. It is therefore expected that increasing connections to global innovation systems accelerates catch-up processes in recently emergent countries. Such connectivity has been demonstrated as a mechanism for catch-up in many national contexts. However, Korea, our empirical context, shows quite different innovation trajectory. Utilizing the patent data from US Patent and Trademark Office (USPTO), we compare the country dispersion of inventors in the electronics and pharmaceutical industry in Korea, Denmark, and Japan to illustrate how globally connected Korea is in terms of new knowledge creation. Our analysis reveals that unlike Denmark, Korea is surprisingly closed to the world when it comes to creation of new knowledge. Its trajectory is similar to that of Japan. Korea's similarity with Japan and its dissimilarity with Denmark in terms of connectivity to global innovation systems at the patent level, suggests that the development of innovation trajectory as well as the general industrialization process of Korea conforms to some extent to the "flying geese model" developed by Kojima.

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INTRODUCTION

The literature on upgrading and catch-up processes in emerging market economies describes the process in which firms from emerging economy markets achieve parity in technological capabilities with firms from advanced economies by proactively investing in upgrading their capabilities (Amsden, 1989; Kumaraswamy, Mudambi, Saranga, & Tripathy, 2012). A critical insight from the catch-up process is that the greater the technological gap existing between a leading country and a following country, the more potential there is for a following country to grow rapidly (Abramovitz, 1986).

The 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. Thereafter, the evidence seems to indicate multiple paths, with some pointing to the importance of building relationships with advanced economy firms to develop adsorptive capacity (Kumaraswamy et al, 2012), while others suggest the importance of developing capabilities in-house through learning-by-doing (Park & Lee, 2006). There is some emprical evidence that even leading firms from emerging economies with a significant presence on global markets have yet to catch-up on innovation capability (Awate, Larsen, & Mudambi, 2012). The relevant question here is whether the skills involved in optimizing the operation of established plants, are also instrumental in achieving the innovation capabilities, skills and technologies necessary to create new products or services (Amsden, 1989).

In catching up with advanced economies and eventually develop innovation capability, access to the sophisticated knowledge countries or regions is of particular importance for firms from developing economies. It follows that catch-up processes at such firms may benefit from engaging in research collaboration with inventors from different backgrounds and perspectives. That is to say, connectivity to other innovation systems in the world is one of the key mechanisms to catch-up. Knolwedge, especially tacit knowledge, is transferred effectviely in the presence of interactions between knowledge transmitter and receiver (Feldman, 1999). Knolwedge shared among inventors through collaboration, hence, becomes critical.

From this perspecitve, Korea provides an interesting empirical context as a successful case of a newly industrialized country or a recent ‘emergent’ economy. Although Korean GDP per capita was much lower than that of Argentina and Brazil in the 1960s and 1970s (World Bank, 2014), it achieved remarkable economic development throughout the 1980s and 1990s, overcoming the middle-income trap (Moreira, 2005). It is now categorized as a high-income economy along with advanced market economics such as the U.S. (The Economist, 2012). Through the evolution over the last three decades, it became a home to some of the world’s best-known companies such as Samsung, the world’s No. 1 smartphone maker with 32% of market share (as of 2013) in global smartphone market (Kovach, 2014). Despite the rapid economic development, when it comes to innovation, it has shown a significantly different trajectory as it is much less connected to the global innovation system compared to other advanced economies. In fact, its developmental trajectory is found to be much similar to that of Japanese, which conforms to some extent to “flying geese model” developed by Kojima (1978).

In this paper, thus, we compare Korea’s developmental trajectory in innovation connectivity with that of some of advanced economies such as Japan and Denmark. Our data relates to 1980-2010 which is the period during which the Korean economy emerged from being poor to become a wealthy economy. Our research question is focused on the Korean innovation system and its relationship to the global innovation system during this period of emergence. We do this mainly by looking at the dispersion of inventor networks in patenting activities. Even though a substantial body of literature on upgrading and catch-up process investigates the actual process of catch-up across different countries, the theoretical lens has been primarly focused on government policy or technological regime rather than on the firm or inventor level. For instance, Amsden (1989) investigates how government policy influences the competitiveness of Korean industries through affecting factor markets. Similarily, Park and Lee (2006) contrast Korea and Taiwan by linking the technological regime to the technological catch-up process at national level. Furthermore, the literature on catch-up, in general, points to upgrade paths of output/innovation capabilities, and yet underlying mechanism behind catch-up process is less explored. In particular, global connectivity in generation of new knowledge by firms in the less developed economies has not been investigated in great detail. Hence, we contribute to the literature by 1) bringing new theoretical lens, i.e., global connectivity to investigate catch-up process, and 2) showing that Korea is surprisingly closed to the world in terms of creation of new knowledge, similar to Japan's trajectory (at least from patent-level analysis), which to best our knowledge has not been studied in any previous work.

In the remainder of this paper, we first discuss previous research that addresses upgrading or catching-up process with particular reference to 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.

THEORETICAL BACKGROUND

Upgrading and Catch-Up Process: Connectivity

An economy's technological capabilities have been emphasized as a fundamental source of heterogeneous development paths observed across countries (Bell & Pavitt, 1997, Castellacci, 2008, Freeman, Clark, & Soete, 1982, Fu, Pietrobelli, & Soete, 2011, Gerschenkron, 1962, Verspagen, 1991). In this regard, a substantial body of literature has described the process of the rapid technological catch-up of emerging countries with developed countries. Firms from emerging economies can simply engage in imitation based on the imported technologies from advanced economies and learning-by-doing rather than innovation, thus achieving output capability at a fast pace (Awate et al., 2012). The key thesis in the previous studies is that, as Abramovitz (1986) argues, the greater the gap in technology and productivity between emerging and advanced economies, the greater the potential for emerging economies to "rapid" catch-up. In other words, contrary to advanced economies, in the case of emerging economies, the marginal effects of the technologies that can be introduced on productivity and growth becomes greater (Hannigan, Lee, & Mudambi, 2013).

Compared to firms from advanced economies, domestic firms in emerging markets are more likely to be technologically and even managerially backward, without much variance in their capabilities and performance (Kumaraswamy et al, 2012). Since they are more likely to have only a limited capacity to generate new indigenous technology (Lall, 1992), it is critical for them to acquire technologies externally (Hannigan et al., 2013) in order to achieve "rapid" catch-up. The positive role of advanced economy multinational enterprises (AMNEs) on the catch-up of emerging economies as an important transmitter of knowledge, particularly technological know-how that is difficult to codify, has been widely supported in the current literature (Ivarsson & Alvstam, 2005; Patibandla & Petersen, 2002; Kogut & Zander, 1993). Indeed, advances in technology have enabled the finer slicing of value chain activities, which are increasingly located in efficient locations around the world (Mudambi, 2008). Being part of global value chains of AMNEs represents a pathway for emerging market economies to participate in global economy: the ability of domestic firms to upgrade skills and make higher level contributions to global value chains is an essential element of emerging market catch-up (Giuliani, Pietrobelli, and Rabellotti, 2005; Humphrey & Schmitz, 2002). This is because AMNEs' coordination of value chain activities requires the continuous mutual exchange of knowledge (Lall, 1980). 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" local firms to develop not only output capabilities (Awate et al., 2012), but eventually innovation capabilities, the skills and technologies necessary to create new products or service (Mathews, 2006).

In catch-up or upgrading process, organizational pipelines serve as the conduits of knowledge that bring disparate sources together (Lorenzen and Mudambi, 2013). This is particularly important as subsidiaries begin to adopt competence-creating mandates (Cantwell and Mudambi, 2005). MNE subsidiaries located in a cluster participate widely in local knowledge sharing by collaborating with firms in a cluster (Lorenzen and Mudambi, 2013), thus helping upgrading local firms. The Bangalore ICT cluster illustrates this point. ICT cluster in Bangalore have developed based on decentralized pipelines which allow local firms to link to MNE partners. Tacit knowledge was transferred to local firms through the mobility of engineers and managers from MNEs (Lorenzen and Mudambi, 2013).

Not only organizational pipelines, but also personal relationships can be another form of mechanism that bring different knowledge from abroad. Hsinchu-Taipei region of Taiwan had been developed as one of the successful information technology cluster primarily in virtue of the connection to Silicon Valley in California through decentralized personal relationships (Saxenian & Hsu, 2001). Specifically, US-educated Taiwanese engineers significantly contributed to the rapid development of this region by not only transferring skill and know-how to Taiwan, but also facilitating collaborations between individual investors, entrepreneurs, and SMEs in the two regions.

The Flying Geese Model

While connectivity to the global innovation system is widely accepted as a mechanism for catch-up in the current literature, there is an exception where connectivity was not a necessary condition for economic progress. Japan is such an exception. Analyzing patent data of OECD countries in a period 1993-1995, Guellec and Van Pottelsberghe de la Potterie (2001) found a trend towards the globalization of technology in OECD countries, which is reflected in the growing number of international co-operation in research and cross-border ownership of technology. While a significant portion of patents are found to be subject to international collaboration, Japan shows lowest degree of openness as very few inventions were made with collaboration with foreign researchers. They attributed its closedness to its big size of domestic market as well as high R&D spending.

Japan has been served as an important reference point to describe the catching-up process of East Asian countries. To explain the industrialization of East Asian countries, “flying geese model” was originally put forward by Akamatsu in the 1930s and further developed later on by Kojima (1978). Similar to the thesis of the product cycle theory developed by Vernon (1966), the central to this model is that the pattern of industrial development is sequentially transmitted from a lead goose (i.e., Japan) to follower geese such as the NIE (i.e., Hong Kong, Singapore, Taiwan and South Korea), to the ASEAN countries (i.e., Indonesia, Malaysia, Philippines, and Thailand), and most recently to China through trade and FDI. As Japanese firms lost comparative advantage in a certain sector, their investment transfer to sunset industries to South Korea and Taiwan, and produce a dynamic regional division of labor as a result (Hill & Fujita, 1996). Simply put, the Japanese developmental trajectory is replicated across neighboring countries in the region in a sequential fashion as they move into higher value-added industries vacated by Japanese firms.

This model has shown explanatory power, in particular, in explaining the catch-up process of South Korea. Indeed, literature shows the similar developmental path between Japan and South Korea. Petri (1988), for instance, suggests that South Korea and Japan, in general, are more comparable in their speed and structure of the development than any other followers in the region. He shows that South Korea's relative comparative advantage in certain sectors are closely correlated with that of Japan with a 15-year time lag, and argues that this was because South Korea consciously set out to the developmental model that Japan had experienced. Further, contrary to other follower countries, the development of both countries has been primarily based on large industrial groups; dominant industrial firms in South Korea and Japan were *chaebols* and *Keiretsu* respectively, all of which are big and diversified firms which possess the access to capital, technology, and world markets (Hannigan et al., 2013). Such evidence suggests the possibility that connectivity may not be necessarily the fundamental mechanism for the catch-up process although it is the widely accepted norm in the literature.

EMPIRICAL ANALYSIS

Research Context

In this paper, we compare a South Korea's leading industry and lagging industry-i.e., electronics and pharmaceutical industry respectively with the same industries in Japan and Denmark. Two industries are at different level of development in three countries. In South Korea, as seen in Figure 1[i], a very high percentage of innovative activities are concentrated in electrical and electronics industry, while minimal innovative activities take place in pharmaceutical industry (drugs & medical). Indeed, South Korean firms have established world-leading market shares in electronics industry (Mundy, 2013). Japan, on the other hand, used to enjoy glory days for the past few decades, having champions such as Sony, Hitachi, Panasonic, and Sharp. Reflecting this, a very high percentage of innovative activities are concentrated in electrical and electronics industry (Figure 2), although now firms in this industry all struggle to compete against rivals such as Samsung and Apple, losing share in global electronics market and even at home (The Economist, 2014). In Denmark, most of innovative activities takes place in pharmaceutical industry (albeit total innovative activities are not as high as both South Korea and Japan), while minimal innovative activities occur in the rest of industries (Figure 3).

Insert Figure 1 about here

Insert Figure 2 about here

Insert Figure 3 about here

South Korean pharmaceutical industry is less developed compared to other competitive industries such as electronics (Oh & Larson, 2011). Specifically, South Korean pharmaceutical market is small in size in comparison with the global market and the industry lacks world-class manufacturing facilities and experience in R&D activities. South Korean pharmaceutical firms generally have difficulty exploring the global market and adapting to new environments (Lee & Song, 2013, Moon, 2012). In fact, they still primarily focus on copying existing drugs rather than inventing new drugs (Moon, 2012). On the contrary, Japan and Denmark have relatively strong position in pharmaceutical industry. Based on strong life science research tradition, the Danish pharmaceutical industry is one of the leading industries in Denmark (Gestrelius, 2008) and is at world-class level after U.S., and some European countries such as Switzerland and Germany. For instance, one of the biggest pharmaceutical companies, Novo Nordisk ranked 21th by revenue as of 2008 (Pharmaceutical Manufacturers Rankings, 2014). In a similar vein, Japan is an advanced economy with the second largest pharmaceutical market behind the US (Buente, Danner, Weissbäcker, & Rammé, 2013, Penner-Hahn & Shaver, 2005), and has some of the big pharmaceutical companies such as Takeda, Daiichi Sankyo, and Astellas Pharma which were ranked within top 20 by sales in 2012 (Noor & Kleinrock, 2013).

The comparison between South Korea, Japan, and Denmark will help us interpret the pattern of global connectivity of South Korean innovation activities. First, with its geographical proximity to South Korea and historical influence on the economic development of South Korea, Japan would be a meaningful benchmark for South Korea. Second, as a small, open, and (longtime) leading innovative economy, Denmark would be a different, but comparable case when studying the connectivity to the world in innovation activities.

Data and Method

Our data comes from Harvard Dataverse Network, which provides inventor-level patent data from US Patent and Trademark Office (USPTO) during the period of 1975-2010[ii] (Li, Lai, D'Amour, Doolin, Sun, Torvik, Yu, & Fleming, 2014). As the data was originally constructed to study inventor mobility and network, 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).

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 electronics and pharmaceutical industry are high-technology industries with active patenting activities (Penner-Hahn & Shaver, 2005), patent-related measures would provide strong insights into invention activities in these industries. We extracted electronics and pharmaceutical patents using the technology classification suggested by Hall, Jaffe, and Trajtenberg (2001). With this dataset, we identify patents that are connected to South Korea, Denmark, and Japan. We do this by identifying the patents that have at least one inventor located in the specific country. Observation of our data consists of 28,518 (electronics) and 2,155 (pharmaceutical), 197,142 (electronics) and 32,657 (pharmaceutical), and 1,417 (electronics) and 3,052 (pharmaceutical) patents for South Korea, Japan, and Denmark respectively.

Once we have done the identification, we construct a measure called country dispersion, following Kollmann, Mudambi, and Tavares-Lehmann (2013). 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.

Next, we calculate degree centrality and betweenness centrality with patent-country network in order to see which countries the patents are mostly connected to. Degree centrality is generally defined as the number of edges that are connected to the node and is normalized by the size of the opposite vertex set in 2-mode network (Borgatti & Everett, 1997). In our case, this means that degree centrality is calculated as the number of patents connected to a certain country, divided by the total number of patents. Betweenness centrality is defined as "the number of geodesic paths that pass through a given node, weighted inversely by the total number of equivalent paths between the same two nodes, including those that do not pass through the given node" (Borgatti and Everett, 1997, p.256). The networks we analyze are patent-'inventor country' 2-mode network for each industry in each country[iii].

Finally, following current literature (e.g., Fleming & Sorenson, 2001, Podolny & Stuart, 1995, Rosenkopf & Nerkar, 2001), we extracted all the backward citations associated with the focal patents that we extracted for both industries in three countries to see where the explicit knowledge comes from for each invention. Inventor country location of the backward citations is analyzed to show the geography of 'codified' knowledge sourcing from previous patents.

Results

Country dispersion of inventors. The country dispersion index of the South Korean, Danish, and Japanese patents in electronics industry and pharmaceutical industry are provided in Tables 1 and 2. As seen, we observe that the level of dispersion of inventors in South Korean and Japanese patents is much lower than that of Danish patents throughout all the years in both industries. Comparing South Korean and Japanese patents, the dispersion index of South Korean patents is higher than that of Japan in general, but it does not show an increasing trend as the dispersion index of Japanese patents does. Although there is stark difference in the level of dispersion in Japanese and Danish patents, the number increases over time for both countries in the two industries. From the period of 1985-1995 to 2005-2010, Danish patents showed 88% and 59% growth in electronics and pharmaceutical industry respectively, while Japanese patents showed 74% and 91% growth. During the same period of time, South Korean patents showed 28% and 36% decrease in dispersion of inventors. Comparing the industries, the dispersion of inventors in pharmaceutical patents is higher than the dispersion in electronics industries for all three countries, which indicates that there is a higher level of inter-country collaboration in the pharmaceutical industry compared to the electronics industry.

The low dispersion level and the decreasing pattern in dispersion over time in South Korea is rather unexpected. As South Korea has developed its technological capabilities tremendously since the 1970s and 80s, one would expect an increasing trend of inventor country dispersion, which can reflect the increasing effort to source advanced knowledge in other countries to enhance the competitiveness. Interestingly, the two industries, one leading industry and one lagging industry in South Korea, show the same pattern in terms of country dispersion of inventors, regardless of the difference in the competitiveness of the two industries in the global market. The difference in the level of dispersion of South Korean patents in the two industries seems to originate from industry-wide pattern, as it is also observed between the two industries in Japan and Denmark. Despite the fact that the development of dispersion level overtime diverges, the general level of dispersion of South Korea and Japan is much similar to each other compared to that of Denmark. For both countries, knowledge sourcing through inter-country inventor collaboration is rather limited.

Insert Table 1 about here

Insert Table 2 about here

Connected countries in the inventor network. To see which countries the focal patents based in South Korea, Japan and Denmark are mostly connected to, degree centrality and betweenness centrality measures are calculated from inventor location network. All in all, the two measures reported in Table 3 and 4 show almost identical sets of collaborating countries for each country.

The U.S. is the country that all three countries are connected to the most in their inventor networks. Considering the technological capabilities of the U.S. in these industries and the data source of our sample (USPTO), a high level of connection to the U.S. is not surprising. The second most collaborating country for South Korean inventors in both industries is Japan although it is to a much lesser degree compared to the level of collaboration with the U.S. inventors. In electronics industry, Singapore is the next most collaborating country while it is China in the case of pharmaceutical industry. Japanese inventors are collaborating mostly with inventors from European countries like Germany, Great

Britain, and France in pharmaceutical industry while they are collaborating to a higher degree with neighboring countries like China and South Korea in electronics industry. Danish inventors collaborate with inventors located in neighboring countries like Germany, Sweden, and Great Britain in both industries. In electronics industry, the inventors are more geographically bounded in terms of inter-country collaboration as they are working mostly with inventors from neighboring or geographically proximate countries if not with the U.S. inventors.

Insert Table 3 about here

Insert Table 4 about here

Inventor location of cited patents. Although knowledge sourcing from abroad through co-inventor network seems to be limited for South Korean patents, there could have been other channels for South Korea to get access to knowledge that resides in other countries. Knowledge contained in previously granted patents can be one source that developing countries can learn from. Reference to the previously granted patent in the patent document (backward citation) shows which previous knowledge a focal patent builds upon in creating new knowledge and where this previous knowledge comes from. Since the patent application process requires that the knowledge related to the patented technology is documented, knowledge sourcing from backward citation represents 'codified' knowledge sourcing as opposed to 'tacit' knowledge sourcing through inventor collaboration. In Table 5 and 6, the inventor location of the patents that are cited by the focal patents is presented[iv]. The countries listed in the table represent the location that provided knowledge base for the focal patents.

Other than the U.S., which accounts for about 40 % and 60% of the inventor location of the backward citation in electronics and pharmaceutical industry, Japan is the country that has the second largest share of inventors in the backward citation of South Korean patents. In electronics industry, the share of Japanese inventors is as high as that of the U.S. inventors, while it is much lower than the share of U.S. inventors in pharmaceutical industry. The share of U.S. inventors is also high in the backward citation of Danish patents as more than half of the total inventors involved in backward citation are from the U.S. In electronics industry, Japan and Germany are the countries that provide the next most important knowledge base for Denmark, but in the case of pharmaceutical industry, the second most important knowledge base is Denmark. Danish pharmaceutical patents cite other patents with Danish inventors to a higher degree compared to Danish electronics patents as 15% of inventors of backward citation are located in Denmark. On the contrary to South Korean and Danish patents, Japanese patents cite patents with Japanese inventors to a higher degree in both industries as the share of Japanese inventors involved in backward citation is the highest. Then, U.S. inventors take up the second largest share. The next three countries have significantly lower share of inventors compared to Japan and the U.S.

Insert Table 5 about here

Insert Table 6 about here

To sum up, the global connectivity of South Korean patents is relatively low and it does not show an increasing trend over time as observed in the patents based in Japan and Denmark. In terms of country dispersion of inventors, South Korean patents show a similar level of dispersion as Japanese patents, which is far from the level of dispersion of Danish patents. What is noticeable about the South Korean patents is that once the patents are connected, they are mostly connected to Japanese inventors, next to the U.S. inventors that are connected heavily to patents from all three countries in comparison. The analysis of inventor location in co-inventor network and backward citation shows that South Korean patents rely relatively heavily on knowledge from Japan. Based on the overall level of connectivity and relatively high connection to Japanese inventors in both electronics and pharmaceutical industry, we suggest that South Korea's development path in the catch-up process seems to follow Japan's path.

Samsung Electronics vs. Sony. Narrowing down our focus to the firm-level, next we compared Samsung Electronics and Sony to see if South Korean firms showed similar pattern as Japanese firms in a technological sense. We chose Samsung Electronics and Sony since they are one of the leading and world-class firms in South Korea and Japan respectively. Samsung Electronics, for instance, accounts for nearly 50 percent of the South Korea's total innovation output, producing 36,647 patents in total, while Sony accounts for about 4% of the Japanese total innovation output, generating 32,918 patents in total.

Insert Figure 4 about here

Insert Figure 5 about here

As seen in Figure 4, there is stark difference between innovation activities of Samsung Electronics and those of Sony over the past three decades. Sony started patenting since 1975, much earlier than Samsung Electronics. Even though Samsung Electronics started patenting much later than Sony - i.e., 1982, its patenting activities grew rapidly over time, finally exceeding the number of patents of Sony starting in 2002. There was a 7 years of lag in terms of initiation of patenting activities between Samsung Electronics and Sony, however, it seems that Samsung Electronics has caught up with Sony these days. In a similar vein, the innovation activities in television division, known as the strongest area of both firms, over time also show the similar trend to that was seen in Figure 5.

Insert Figure 6 about here

Narrowing our focus further down to much smaller technological area, in Flat Panel Display (FPD) segment, we observe the similar pattern in Figure 6. Technological development in FPD segment had been initiated in Japan, as 90 % of TFT LCD production took place in Japan in early years of development (Murtha, Lenway, & Hart, 2001). Then, in the mid-1990s, large South Korean companies such as Samsung and LG initiated the second wave of high-volume FPD production from outside of

Japan by aggressively acquiring technologies through alliances, acquisitions, and licensing agreements etc. By 2000, as a result, more than 36% of global TFT LCD production took place in South Korea, and Samsung became a leading company in this sector. Reflecting this, we observe steep increase in the patenting activities of Samsung Electronics after 2000. Contrary to this, the patenting activities of Sony had been fluctuated, even decreased more recently. This divergent developmental path was partly due to differences in strategic flexibility in the sense that biased towards its home market, Sony stuck with its Trinitron televisions even after flat-panel TVs had won the market, while Samsung Electronics had actively invested in this business and pursued parallel development strategy which facilitated time-to-market (Chang, 2008). Same as the global connectivity observed previously in South Korea and Japan, the average global connectivity for Samsung Electronics and Sony are relatively low and they do not show an increasing trend over time.

DISCUSSION AND CONCLUSION

The findings in this paper show that the global connectivity of South Korean patents is relatively low and it does not show an increasing trend over time as observed in the patents based in Japan and Denmark. More specifically, in terms of country dispersion of inventors, South Korean patents show a similar level of dispersion as Japanese patents, which is far from the level of dispersion of Danish patents. This is a rather unexpected pattern of globalization of innovation for a country like South Korea. As one of the newly industrialized countries (NICs) that has demonstrated rapid growth throughout 1980s and 1990s (Moreira, 1995), one could expect firms with South Korea-based patents (which are mainly South Korean firms) to have developed sufficient innovative capabilities over time to actively reach out advanced knowledge in foreign locations and combine it with indigenous knowledge.

One explanation could be that ‘catching-up’ in terms of globalizing (and therefore coordinating geographically scattered) innovation activities takes time and that South Korean pharmaceutical firms have yet developed these capabilities to the same degree as firms from advanced economies. Pharmaceutical industry is still in the early stage of catching-up with only recent support from the government (Moon, 2012) and therefore the innovation capabilities in this industry can be immature. However, one problem with this explanation is that it seems to lose its power when we compare the country dispersion index in pharmaceutical industry between South Korea and Japan and the country dispersion index between pharmaceutical industry and electronics industry in South Korea. Despite the level of development in pharmaceutical industry, Japan shows even lower level of country dispersion index. Furthermore, some South Korean firms in the electronics industry like Samsung and LG have become leading firms in the sector with advanced technologies and own a large portion of South Korea-based patents in this industry, but their innovation activities are even less dispersed geographically than those of pharmaceutical firms. However, considering that South Korean electronics firms have developed their competitiveness based on manufacturing capabilities as component suppliers to leading firms in the advanced economies in international production networks (Ernst & Guerrieri, 1998), one could argue that their innovative effort may have remained within the domain of manufacturing excellence rather than that of new product development. This could imply that South Korea still has immature innovative capabilities, which in turn could be the explanation for the lack of global connectivity in its innovation activities.

Observing the similar low level of dispersion of Japanese electronics and pharmaceutical patents (although with increasing trend over time), we can then speculate whether or not this low level of globally-connected innovation activity show that these East Asian countries have developed some distinctive patterns of innovation activities over time, resulting from the analogous economic development pattern suggested by the ‘flying geese (FG)’ model. As reviewed previously, FG model suggests that latecomer economies achieve catching-up following a couple of sequential stages in which a single industry grows through import-production-export cycle, which is then followed by diversification of the industry and upgrade of the products. One aspect that has especially been highlighted in the model is that this pattern of economic development are transmitted to other less-developed follower ‘geese’ in the region. In the case of East Asian countries, South Korea as one of the following geese seems to have closely traced the development pattern of Japan, which could also explain the similar pattern of innovation trajectory of the two countries[v]. The measures that we have looked at illustrate very focused and centralized innovation activities by South Korean and Japanese firms. The fact that very small percentage of patents have inventors located abroad indicates that their innovation activities are geographically bounded to home country and these firms prefer to have full control of their innovation activities in geographical proximity. This very similar developmental pattern of two countries may be due to the fact that South Korean government consciously followed Japanese industrialization experience (Petri, 1988). To buttress this, the analysis of inventor location in co-inventor network and backward citation shows that South Korean patents rely relatively heavily on knowledge from Japan. Based on the overall level of connectivity and relatively high connection to Japanese inventors in both electronics and pharmaceutical industry, we suggest that South Korea's developmental path in the catch-up process seems to converge to Japan's developmental path (albeit not exactly same), not to Denmark's developmental path. Despite of criticism over the years, it seems that FG model still has an explanatory power at least for South Korea.

Although our analysis seems to confirm the rationale of FG model, there could be possibility that the internationalization of innovation activities of countries may not be fully captured by our measures. Considering that catching-up often requires access to and 'learning' from advanced technologies abroad, innovation activities of the catching-up countries may inevitably have some international dimension. However, there are different mechanisms of international technology transfer that will not be detected in our measures. 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. For South Korean case, the movement of people can especially be relevant as it is common for South Koreans to get higher education abroad and return home after education. For example, Samsung is well known for recruiting a large number of R&D employees with foreign degrees (Chang, 2008). In this way, firms are sourcing knowledge internationally, but it will not show in the measures in our analysis. Similarly, licensing could have been another mechanism through which South Korean firms source knowledge and this would not be reflected in our global connectivity measure.

One future avenue that we could explore is to analyze the quality of South Korean patents. Based on our findings, one may conjecture that South Korea has not been catch up on sophisticated innovation capability yet even though it seems to fully catch up in terms of the number of patents generated over time. To see if it reached innovation capability in more detail, we could analyze if it creates impactful innovations rather than incremental innovations. Another avenue that we could explore in the future is to look at different data rather than patent data. As discussed above, foreign knowledge can be flown through different types of mechanisms such as licensing contract. By looking at different types of knowledge flow mechanism, we could capture global knowledge sourcing activities that we could not capture from patent data.

REFERENCES

Abramovitz, M. 1986. Catching up, forging ahead, and falling behind. *The Journal of Economic History*, 46(02): 385-406.

Amsden, A. (1989). *Asia's next giant: South Korea and late industrialization*: Oxford University Press.

Awate, S., Larsen, M. M., & Mudambi, R. 2012. EMNE catch-up strategies in the wind turbine industry: Is there a trade-off between output and innovation capabilities? *Global Strategy Journal*, 2(3): 205-23.

Bell, M. & Pavitt, K. 1997. Technological accumulation and industrial growth: contrasts between developed and developing countries. *Technology, globalisation and economic performance*: 83-137.

Bernard, M. & Ravenhill, J. 1995. Beyond product cycles and flying geese: regionalization, hierarchy, and the industrialization of East Asia. *World Politics*, 47(02): 171-209.

Bierly, P. & Chakrabarti, A. 1996. Generic knowledge strategies in the US pharmaceutical industry. *Strategic Management Journal*, 17(S2): 123-35.

Borgatti, S. P. & Everett, M. G. 1997. Network analysis of 2-mode data. *Social networks*, 19(3): 243-69.

Breschi, S. & Lissoni, F. 2009. Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows. *Journal of Economic Geography*.

Bruton, G. D., Ahlstrom, D., & Wan, J. C. 2003. Turnaround in East Asian firms: Evidence from ethnic overseas Chinese communities. *Strategic Management Journal*, 24(6): 519-40.

Buente M, Danner S, Weissbäcker S, Rammé S. 2013. *Pharma Emerging Markets 2.0: How Emerging Markets Are Driving the Transformation of the Pharmaceutical Industry,* Booze & Company

Emerging Markets Are Driving the Transformation of the Pharmaceutical Industry. *Booze & Company*.

Cantwell, J. 1995. The globalisation of technology: what remains of the product cycle model? *Cambridge Journal of Economics*, 19: 155-55.

Cantwell, J. 1989. Technological innovation and multinational corporations.

Cantwell, J., & Mudambi, R. (2005). MNE competence-creating subsidiary mandates. Strategic management journal, 26(12), 1109-1128.

Cantwell, J. & Zhang, F. 2013. Do Foreign-owned Subsidiaries in China Follow a Distinctive Pattern of Technological Knowledge Sourcing? . *Management and Organization Review*, 9(3): 489-512.

Castellacci, F. 2008. Technology clubs, technology gaps and growth trajectories. *Structural Change and Economic Dynamics*, 19(4): 301-14.

Chang, S.-J. 2008. *Sony vs Samsung: The Inside Story of the Electronics Giants' Battle For Global Supremacy*: John Wiley & Sons.

Dowlinga, M. & Cheang, C. T. 2000. Shifting comparative advantage in Asia: new tests of the "flying geese" model. *Journal of Asian Economics*, 11(4): 443-63.

Ernst, D. & Guerrieri, P. 1998. International production networks and changing trade patterns in East Asia: The case of the electronics industry. *Oxford Development Studies*, 26(2): 191-212.

Feldman, M. P. 1999. The new economics of innovation, spillovers and agglomeration: Areview of empirical studies. *Economics of innovation and new technology*, 8(1-2): 5-25.

Fleming, L. & Sorenson, O. 2001. Technology as a complex adaptive system: evidence from patent data. *Research Policy*, 30(7): 1019-39.

Freeman, C., Clark, J., & Soete, L. 1982. *Unemployment and technical innovation: a study of long waves and economic development*: Frances Pinter London.

Fu, X., Pietrobelli, C., & Soete, L. 2011. The role of foreign technology and indigenous innovation in the emerging economies: Technological change and catching-up. *World development*, 39(7): 1204-12.

Gerschenkron, A. 1962. Economic backwardness in historical perspective. *Economic backwardness in historical perspective.*

Gestrelius, S. 2008. *Why is Danish life science thriving?: a case study of the life science industry in Denmark*: VINNOVA.

Ginzburg, A. & Simonazzi, A. 2005. Patterns of industrialization and the flying geese model: the case of electronics in East Asia. *Journal of Asian Economics*, 15(6): 1051-78.

Giuliani, E., Pietrobelli, C., & Rabellotti, R. 2005. Upgrading in global value chains: lessons from Latin American clusters. *World development*, 33(4): 549-73.

Griliches, Z. 1998. Patent statistics as economic indicators: a survey, *R&D and productivity: the econometric evidence*: University of Chicago Press.

Guellec, D. & Van Pottelsberghe de la Potterie, B. 2001. The internationalisation of technology analysed with patent data. *Research Policy*, 30(8): 1253-66.

Hall, B. H., Jaffe, A. B., & Trajtenberg, M. 2001. The NBER patent citation data file: Lessons, insights and methodological tools: National Bureau of Economic Research.

Hannigan, T., Lee, A., & Mudambi, R. 2013. The pitfalls of an inward-oriented economy: lessons from the evolution of Brazil and the Republic of Korea. *Transnational Corporations*, 22(2).

Hart-Landsberg, M. & Burkett, P. 1998. Contradictions of capitalist industrialization in East Asia: a critique of “flying geese” theories of development. *Economic Geography*, 74(2): 87-110.

Henderson, R. & Cockburn, I. 1994. Measuring competence? Exploring firm effects in pharmaceutical research. *Strategic Management Journal*, 15(S1): 63-84.

Child-Hill, R., & Fujita, K. (1996). Flying geese, swarming sparrows of preying hawk. Perspectives on East Asian industrialization. *Competition and Change*, 1(3).

Hobday, M. 1994. Innovation in East Asia: diversity and development. *The handbook of industrial innovation*.

Ivarsson, I. & Alvstam, C. G. 2005. Technology transfer from TNCs to local suppliers in developing countries: a study of AB Volvo’s truck and bus plants in Brazil, China, India, and Mexico. *World development*, 33(8): 1325-44.

Kogut, B., & Zander, U. (1993). Knowledge of the firm and the evolutionary theory of the multinational corporation. Journal of international business studies, 625-645.

Kojima, K. 1978. *Direct foreign investment: A Japanese model of multinational business operations*: Croom Helm London.

Kollmann, M. F. C., Mudambi, R., & Tavares-Lehmann, A. T. 2013. Innovation networks in peripheral economies: The case of Portugal.

Kovach S. 2013. Retrieved from http://www.businessinsider.com/samsung-apple-smartphone-market-share-2013-11. [8 July 2014].

Kumaraswamy, A., Mudambi, R., Saranga, H., & Tripathy, A. 2012. Catch-up strategies in the Indian auto components industry: Domestic firms' responses to market liberalization. *Journal of international business studies*, 43(4): 368-95.

Lall, S. 1992. Technological capabilities and industrialization. *World development*, 20(2): 165-86.

Lall, S. 1980. VERTICAL INTER-FIRM LINKAGES IN LDCs: AN EMPIRICAL STUDY*. *Oxford bulletin of Economics and Statistics*, 42(3): 203-26.

Lee, W. & Song, Y. C. 2013. The Strategy of Cooperation and Competition Based on Comparative Analyses of Pharmaceutical Industries of Korea and India. *KIEP Research Paper No. World Economy Updates-13-47*.

Li, G.-C., Lai, R., D'Amour, A., Doolin, D. M., Sun, Y., Torvik, V. I., Yu, A. Z., & Fleming, L. 2014. Disambiguation and co-authorship networks of the US patent inventor database (1975–2010). *Research Policy*, 43(6): 941-55.

Lorenzen, M., & Mudambi, R. (2013). Clusters, connectivity and catch-up: Bollywood and Bangalore in the global economy. *Journal of Economic Geography,* 13(3): 501-534.

Maskell, P. & Malmberg, A. 1999. Localised learning and industrial competitiveness. *Cambridge Journal of Economics*, 23(2): 167-85.

Mathews, J. A. 2006. Dragon multinationals: New players in 21st century globalization. *Asia Pacific journal of management*, 23(1): 5-27.

Moon, H.-S. 2012. *The Effect of Government Policies on the Innovation Performance of Korean Pharmaceutical Industry*: KIET.

Moreira, M. M. 1995. *Industrialization, trade and market failures: the role of government intervention in Brazil and South Korea*: St. Martin's Press.

Mundy, S. (2013). South South South Korea shipbuilders harness much-needed tailwind. RetrievedSeptember 29, 2014, from http://www.ft.com/cms/s/0/afbf7bfe-37e0-11e3-8668 00144feab7de.html#axzz3EjzM0Ziw

Murtha, T. P., Lenway, S. A., & Hart, J. A. 2001. *Managing new industry creation: Global knowledge formation and entrepreneurship in high technology*: Stanford University Press.

Noor W, Kleinrock M. 2013. Pharma 50. Retrieved from http://www.imsconsultinggroup.com/deployedfiles/consulting/Global/Content/How%20We%20Help/Strategy%20&%20Portfolio/PharmExec-pharma50.pdf. [9 July 2014].

Oh, M. & Larson, J. 2011. *Digital development in Korea: Building an information society*: Taylor & Francis.

Park, K.-H., & Lee, K. (2006). Linking the technological regime to the technological catch-up: analyzing Korea and Taiwan using the US patent data. *Industrial and Corporate Change*, 15(4), 715-753.

Patibandla, M., & Petersen, B. (2002). Role of transnational corporations in the evolution of a high-tech industry: The case of India's software industry. World Development, 30(9), 1561-1577.

Penner-Hahn, J. & Shaver, J. M. 2005. Does international research and development increase patent output? An analysis of Japanese pharmaceutical firms. *Strategic Management Journal*, 26(2): 121-40.

Petri, P. A. 1988. Korea's export niche: Origins and prospects. *World development*, 16(1): 47-63.

Pharmaceutical Manufacturers Rankings. 2014. Retrieved from http://www.justpharmaceutical.com/industry/rankings.htm. [2 July 2014].

Phene, A., Fladmoe-Lindquist, K., & Marsh, L. 2006. Breakthrough innovations in the US biotechnology industry: the effects of technological space and geographic origin. *Strategic Management Journal*, 27(4): 369-88.

Podolny, J. M. & Stuart, T. E. 1995. A role-based ecology of technological change. *American Journal of Sociology*: 1224-60.

Reed, R. & DeFillippi, R. J. 1990. Causal ambiguity, barriers to imitation, and sustainable competitive advantage. *Academy of management review*, 15(1): 88-102.

Rosenkopf, L. & Almeida, P. 2003. Overcoming local search through alliances and mobility. *Management science*, 49(6): 751-66.

Rosenkopf, L. & Nerkar, A. 2001. Beyond local search: boundary-spanning, exploration, and impact in the optical disk industry. *Strategic Management Journal*, 22(4): 287-306.

Saxenian, A., & Hsu, J. Y. (2001). The Silicon Valley–Hsinchu connection: technical communities and industrial upgrading. Industrial and corporate change, 10(4), 893-920.

The Economist. 2012. Retrieved from http://www.economist.com/blogs/graphicdetail/2012/03/focus-3. [8 July 2014].

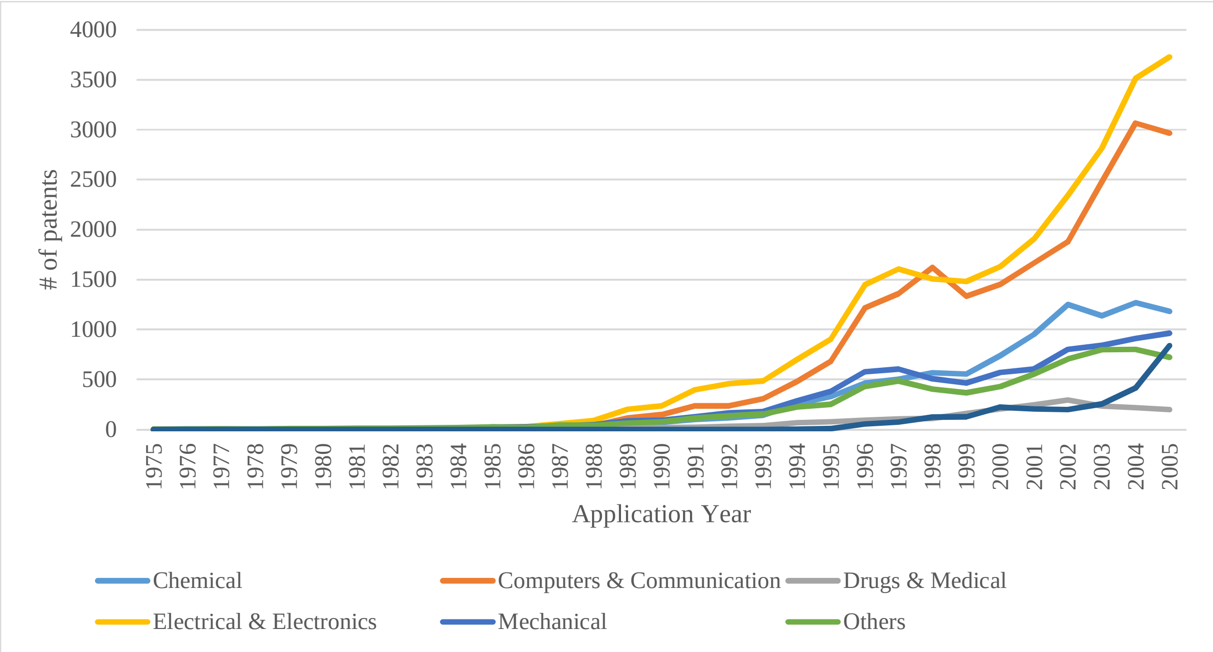
Vernon, R. 1966. International investment and international trade in the product cycle. *The quarterly journal of economics*: 190-207.

Verspagen, B. 1991. A new empirical approach to catching up or falling behind. *Structural Change and Economic Dynamics*, 2(2): 359-80.Verspagen, B. & Schoenmakers, W. 2004. The spatial dimension of patenting by multinational firms in Europe. *Journal of Economic Geography*, 4(1): 23-42.

World Bank. Retrieved from http://data.worldbank.org/. [8 July 2014].

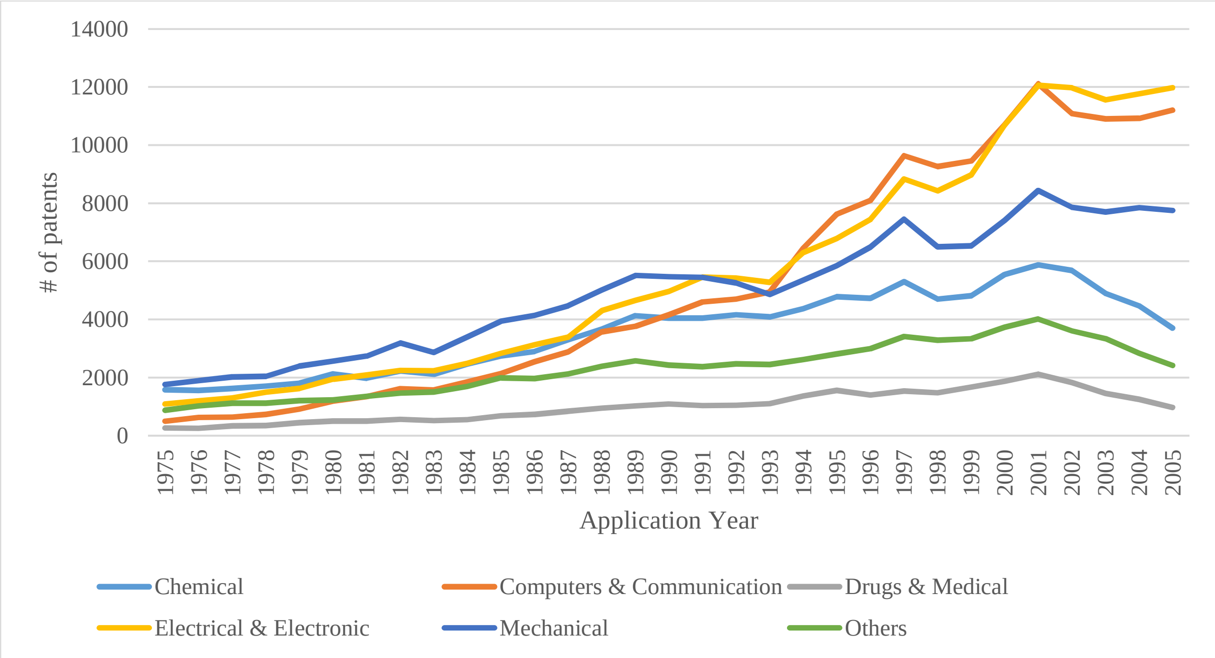
APPENDIX

Figure 1. Industrial focus of South Korea



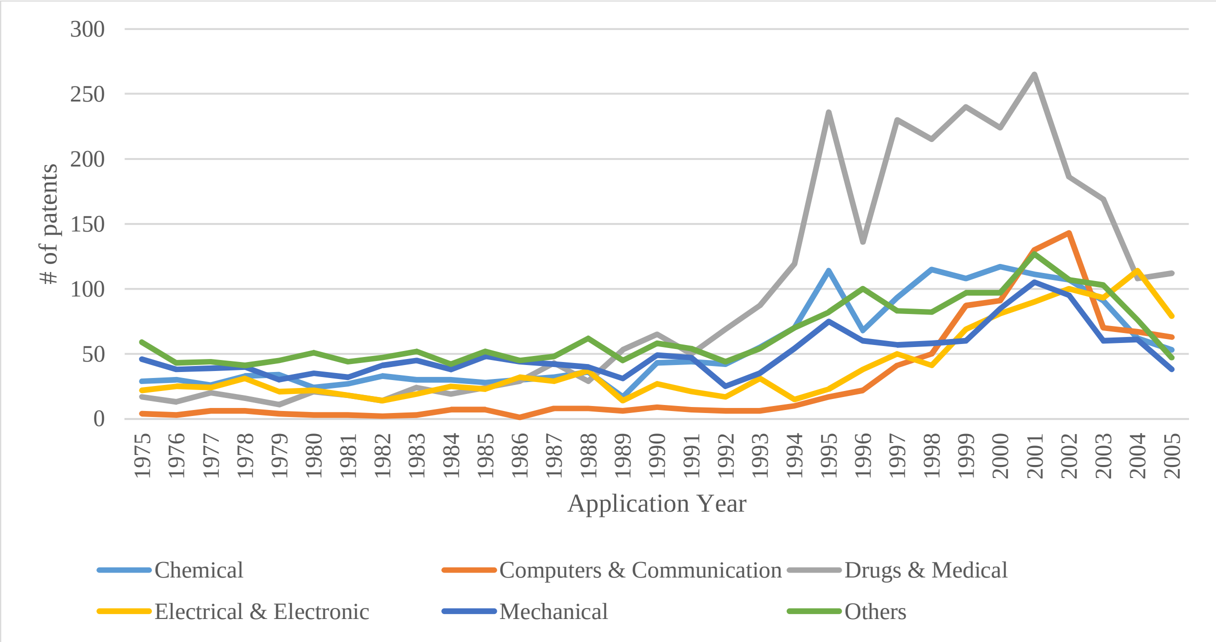
Source: Authors' analysis of U.S. Patent and Trademark Office data.

Figure 2. Industrial focus of Japan



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

Figure 3. Industrial focus of Denmark



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

Table 1 Country dispersion of inventors in electronics industry

	South Korea		Japan		Denmark	
Year	Obs	Mean	Obs	Mean	Obs	Mean
1975-1984	30	0.063	17719	0.002	221	0.018
1985-1994	2222	0.016	45746	0.005	246	0.065
1995-2004	15837	0.010	98481	0.008	690	0.075
2005-2010	10428	0.011	35195	0.008	221	0.122
Total	28517	0.025	197141	0.006	1378	0.070

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

Table 2 Country dispersion of inventors in pharmaceutical industry

	South Korea		Japan		Denmark	
Year	Obs	Mean	Obs	Mean	Obs	Mean
1975-1984	15	0.067	4275	0.013	173	0.054
1985-1994	176	0.082	9844	0.023	568	0.098
1995-2004	1555	0.070	16207	0.038	2008	0.145
2005-2010	409	0.053	2331	0.044	284	0.156
Total	2155	0.068	32657	0.029	3033	0.113

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

Table 3 Degree and betweenness centrality measure for inventor network in the electronics industry

South Korea				Japan				Denmark			
Degree		Betweenness		Degree		Betweenness		Degree		Betweenness	
US	0.0187	US	0.00018	US	0.012975	US	8.84E-05	US	0.068892	US	0.002372
JP	0.003069	JP	4.66E-06	GB	0.001518	GB	1.34E-06	DE	0.023438	DE	0.000267
SG	0.00163	SG	1.60E-06	CN	0.00129	CN	7.63E-07	SE	0.015625	SE	0.000129
RU	0.001055	RU	4.89E-07	KR	0.000835	KR	3.09E-07	GB	0.010653	GB	5.86E-05
GB	0.000671	GB	2.74E-07	CA	0.000607	CA	2.20E-07	NL	0.007813	NL	2.98E-05
DE	0.000575	DE	1.34E-07	FR	0.000531	FR	1.54E-07	FI	0.004972	FI	1.18E-05
CN	0.000479	CN	1.05E-07	DE	0.000455	DE	1.21E-07	IL	0.004261	IL	7.31E-06
PH	0.000479	PH	1.01E-07	SG	0.000455	SG	8.44E-08	JP	0.004261	JP	7.31E-06
MY	0.000384	MY	7.78E-08	TW	0.000379	AU	5.84E-08	BE	0.003551	CH	6.22E-06
AT	0.000288	IN	3.64E-08	AU	0.000304	TW	5.60E-08	CH	0.003551	BE	4.87E-06

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

Table 4 Degree and betweenness centrality measure for inventor network in the pharmaceutical industry

South Korea				Japan				Denmark			
Degree		Betweenness		Degree		Betweenness		Degree		Betweenness	
US	0.134107	US	0.009420	US	0.064323	US	0.002131	US	0.127457	US	0.008252
JP	0.013457	JP	0.000094	DE	0.009754	DE	0.000048	SE	0.059633	SE	0.001764
CN	0.006961	CN	0.000021	GB	0.005153	GB	0.000014	DE	0.043578	DE	0.000974
CA	0.006032	CA	0.000016	FR	0.003405	FR	0.000006	GB	0.024902	GB	0.000336
RU	0.005104	RU	0.000014	CA	0.002853	CA	0.000004	NL	0.017038	NL	0.000147
DE	0.003712	DE	0.000007	CH	0.002761	CH	0.000004	JP	0.011796	JP	0.000066
CH	0.002784	CH	0.000004	CN	0.002301	CN	0.000003	NO	0.008519	NO	0.000033
GB	0.002784	GB	0.000003	KR	0.001564	KR	0.000001	FR	0.008191	FR	0.000032
FR	0.001856	FR	0.000001	DK	0.001472	DK	0.000001	CH	0.007536	CZ	0.000027
IT	0.001392	IT	0.000001	IL	0.001012	IL	0.000000	CZ	0.007536	CH	0.000027

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

Table 5 Inventor location of backward citation in electronics industry

KR Electronics			JP Electronics			DK Electronics		
Country	Freq.	Percent	Country	Freq.	Percent	Country	Freq.	Percent
US	152,205	38.27	JP	1,230,994	59.16	US	11,937	56.76
JP	147,520	37.09	US	613,063	29.46	JP	3935	18.71
KR	44,913	11.29	DE	59,558	2.86	DE	1454	6.91
TW	23,491	5.91	KR	39,371	1.89	DK	867	4.12
DE	7,153	1.8	TW	35,026	1.68	FR	436	2.07

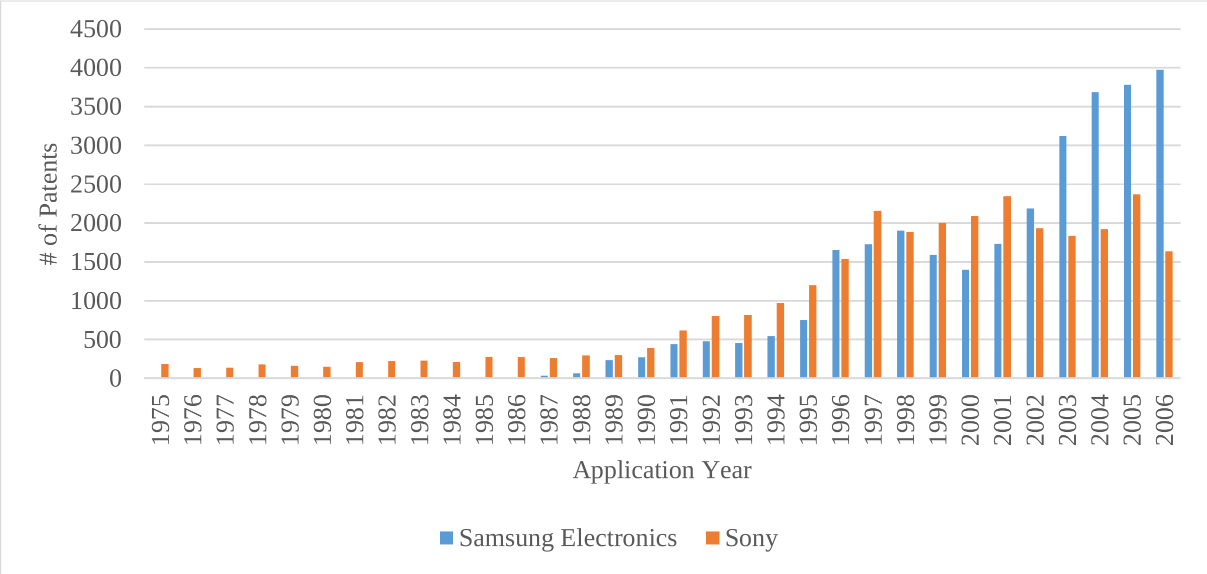
Source: Authors' analysis of U.S. Patent and Trademark Office data.

Table 6 Inventor location of backward citation in pharmaceutical industry

KR Pharma			JP Pharma			DK Pharma		
Country	Freq.	Percent	Country	Freq.	Percent	Country	Freq.	Percent
US	17,853	61.83	JP	106,276	49.12	US	32,413	56.61
JP	3,451	11.95	US	71,273	32.94	DK	8,661	15.13
KR	1,605	5.56	DE	11,219	5.19	JP	4,117	7.19
DE	1,403	4.86	GB	5,047	2.33	DE	3,309	5.78
GB	827	2.86	FR	4,555	2.11	GB	1,691	2.95

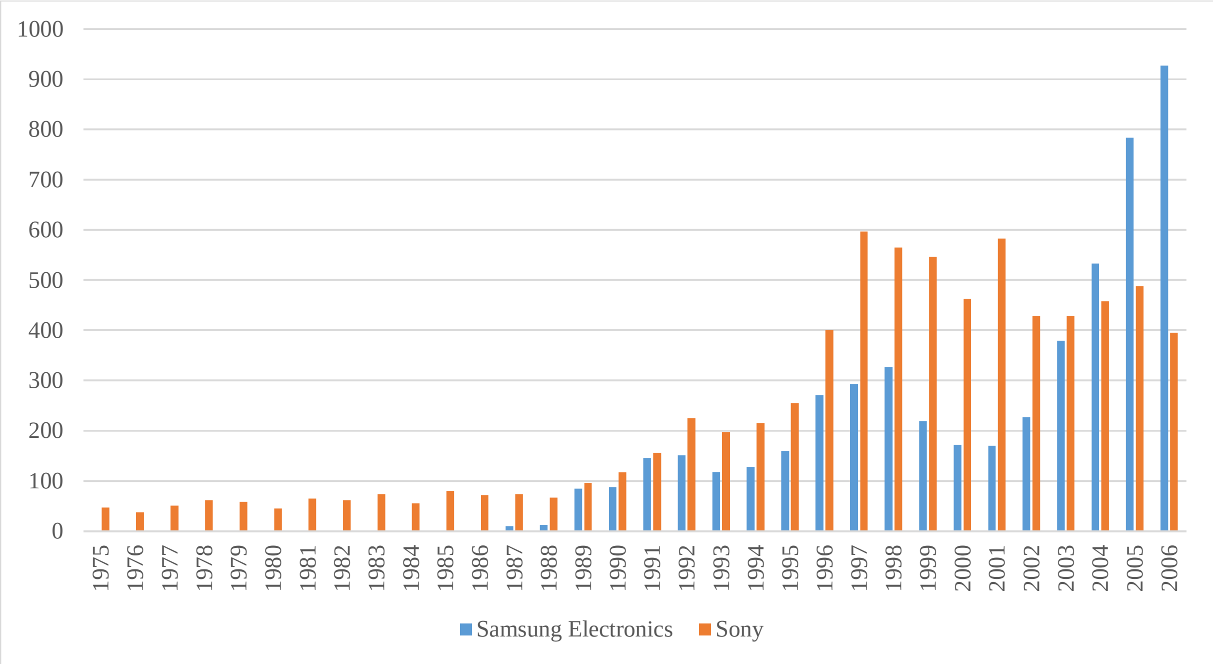
Source: Authors' analysis of U.S. Patent and Trademark Office data.

Figure 4. Number of USPTO Patents of Samsung Electronics and Sony, 1975-2006 (all industries)



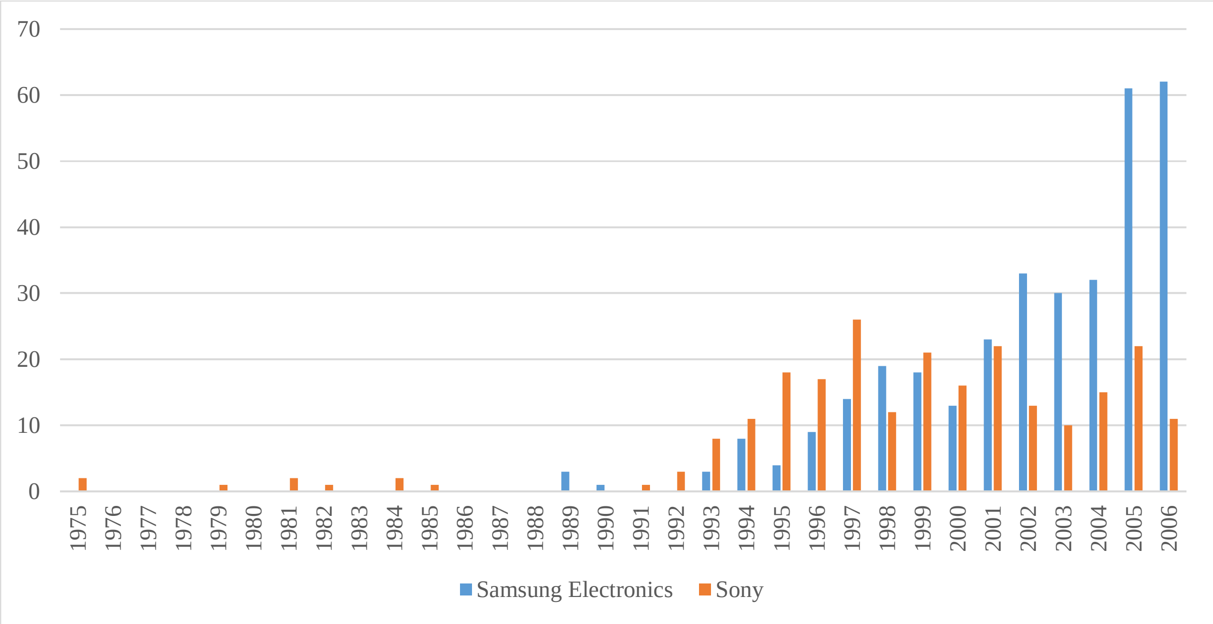
Source: Authors' analysis of U.S. Patent and Trademark Office data.

Figure 5. Number of USPTO Patents Samsung Electronics and Sony, 1975-2006 (Television)



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

Figure 6. Number of USPTO Patents Samsung Electronics and Sony, 1975-2006 (Flat Panel Display)



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

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[i] Industrial categorization was based on Hall, Jaffe, and Trajtenberg (2001).

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

[iii] Due to the large size of the samples and the memory limitation in the network analysis software, analysis for the whole sample of patents is not possible for South Korean electronics industry and Japanese pharmaceutical and electronics industry. Therefore, the centrality measures were calculated for the most recent 10,000 patents (approximately) for these industries. For South Korean electronics industry, patents applied from 2005 to 2010 are included. For Japanese pharmaceutical industry and electronics industry, patents applied from 2000 and onwards and 2007 and onwards are included, respectively.

[iv] The country location of each inventor on a patent is counted separately in order to account for all the countries that are associated with the patent. If a patent is cited by more than one focal patent, the countries are counted multiple times to incorporate the importance of the inventor country as a knowledge source.

[v] Although not included here, our analysis on China-based patents shows that the global connectivity of Chinese patents is relatively high and increases rapidly over time, confirming different developmental path from South Korea.