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Catch-up and connectivity to global innovation system: Focusing on business groups in newly industrialized countries in East Asia

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Abstract

Sourcing diverse sets of knowledge globally through co-inventor networks constitutes an opportunity for innovation catch-up for less developed countries. In this paper, we analyze global connectivity of Korea and Taiwan, the two Asian economies that achieved remarkable economic development in a short period of time, in terms of co-inventor network during their catch-up period from 1980 to 2010. Unlike our expectation that the two economies may have utilized active knowledge sourcing through co-inventor networks during their catch-up process, our analysis suggests that these two countries are not well-connected to the rest of the world when it comes to innovation networks. Further analyses show that, business groups in these countries show different patterns with regards to connectivity to the global innovation system. Korean business groups are relatively 'closed and focused' in their innovation effort whereas Taiwanese business groups are more likely to be connected globally. As business groups in these two economies constitute a large share of their resoective economy and have been the primary engine for economic catch-up, understanding their connectivity to the global innovation system and the factors that led to this pattern is of great importance in studying innovation capability building of late-comer economies.
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Abstract

Sourcing diverse sets of knowledge globally through co-inventor networks constitutes an opportunity for innovation catch-up for less developed countries. In this paper, we analyze global connectivity of Korea and Taiwan, the two Asian economies that achieved remarkable economic development in a short period of time, in terms of co-inventor network during their catch-up period from 1980 to 2010. Unlike our expectation that the two economies may have utilized active knowledge sourcing through co-inventor networks during their catch-up process, our analysis suggests that these two countries are not well-connected to the rest of the world when it comes to innovation networks. Further analyses show that, business groups in these countries show different patterns with regards to connectivity to the global innovation system. Korean business groups are relatively 'closed and focused' in their innovation effort whereas Taiwanese business groups are more likely to be connected globally. As business groups in these two economies constitute a large share of their resoective economy and have been the primary engine for economic catch-up, understanding their connectivity to the global innovation system and the factors that led to this pattern is of great importance in studying innovation capability building of late-comer economies.

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 Korea and Taiwan, among the newly industrialized economies, in particular, is quite impressive given the fact that majority of the developing countries made a little progress in catching up. In Korea and Taiwan, the electronics industry has been a backbone of the economy. Indeed, Korean firms have established world-leading market shares in electronics industry (Mundy, 2013; Lee & Lim, 2001) becoming a home for global companies such as Samsung Electronics and LG. Similarly, Taiwan is a home for global companies such as Acer and HTC.

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 manageriabl 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; Patibandla & Petersen, 2002; Kogut & Zander, 1993).

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 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 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, 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 (Mudambi & Lorenzen, 2013), is particularly relevant to study in relation to catch-up in innovation capability. Especially, the type of linkages that involves personal interactions and thereby facilitates transfer of tacit knowledge will be utmost beneficial for building innovation capability. Thus, we study the global linkage in terms of co-inventor network, which is based on personal interaction, in the context of technological catch-up of Korea and Taiwan.

In discussing catch-up of the two newly industrialized economies, one cannot neglect the contribution of business groups that have largely driven the economic development over the past few decades. At their peak in the late 1990s, the proportions of the aggregated sales of Korean and Taiwanese business groups to GNP reached 97.6% and 55.6% respectively (Chang, Chung & Mahmood, 2006). Their contribution to knowledge production shows a similar pattern in that about 86% of Korean patents and 35% of Taiwanese patents in electronics industry granted by US Patent and Trademark Office (USPTO) during the last three decades are owned by business groups[1].

[1] The authors' calculation based on the data used in this paper.

Therefore, studying the connectivity patterns of business groups will enhance the understanding of global connectivity of the two economies as a whole.

Our analysis shows that despite the remarkable development in their technological 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, due to the different characteristics of business groups in these countires, Korean business groups and Taiwanese business groups show different inclination on sourcing knowledge globally. Overall, our findings contribute to understanding the catch-up process of Korea and Taiwan in relation to their global connectivity in innovation space. Despite its potentially positive impact on innovation capability building, co-inventor connectivity has not been studied in catch-up of emerging economies (Giuliani, Martinelli, & Rabellotti, 2016), not to mention Korea and Taiwan- the focus of our paper. Moreover, we direct our focus on innovation capability catch-up rather than output capability catch-up, which a susbtantial volume of catch-up literature has been focusing on.

The rest of this paper proceeds as follows. The next section provides theoretical background and presents our hypothesis. 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.

THEORETICAL BACKGROUND

Catch-up and capability building

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) 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 process. 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 can be 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. For example, firms can be connected to the source of new knowledge through organizational linkages or pipelines (Bathelt, Malmberg, & Maskell, 2004) and person-based linkages (Saxenian & Hsu, 2001) or epistemic communities (Lissoni, 2001).

In local firms' output capability building, advanced economy multinational enterprises (AMNEs) can be the main conduit of knowledge movement. 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 MNCs 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 global production network (GPN) helps local firms to build capabilities as MNEs from advanced economies 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 MNEs from advanced economies transfer technical and managerial knowledge to the local suppliers. In 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 (started as OEM contractor for the MNEs and progress gradually to OEM, ODM, and finally OBM) 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 can progressively move on to build innovation capability. Even if local firms catch up with output capability, firms in less-advanced economies could still have a relatively narrow sets of technologies and a limited capacity to generate new indigenous technology on their own (Lall, 1992). As less-advanced economies catch up, to sustain growth, they need to become innovators rather than imitators (Kim, 1997). 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 utmost important for them to get access continuously to knowledge residing abroad in order to create innovation (Hannigan, Cano-Kollmann, & Mudambi, 2015). To reflect this, recent studies pointed out that firms from emerging economies are increasingly connected to global innovation networks through international R&D collaborations and/or cross-border inventions (Giuliani, Martinelli, & Rabellotti, 2016; Montobbio & Sterzi, 2013). Sourcing external knowledge 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.

In this context, the connectivity that allows sharing of tacit knowledge is especially beneficial as tacit knowledge is considered as a key ingredient for innovation. Tacit knowledge in general requires direct communication among individuals such as fact-to-face contacts and interpersonal meetings since it is usually embodied in individuals (Feldman & Audretsch, 1999). Unlike codified media, therefore, working on a certain project with inventors from different national or even regional context increases the chance of accessing such tacit knowledge. Previous studies on co-inventor networks in patenting activities highlight importance of interpersonal connection in knowledge flows (Breschi & Lissoni, 2009; Singh, 2005). Personal relations through co-inventorship is also likely to have long-term influence on continuous knowledge exchange as it is found that inventors continue to cite their former collaborators' invention even after they move from one region to another (Agrawal et al., 2003). We would therefore expect that newly industrialized economies that have achieved technological catch-up over the last few decades utilized a relatively high level of knowledge sourcing through this form of direct collaboration in the process of catch-up.

The role of business groups in catch-up and global connectivity

Business groups, defined as "a gathering of formally independent firms under the single common administrative and financial control of one family" (Chang & Hong, 2000), have been 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 the government policy. 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 accounted 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 (SMEs) (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, 1989).

However, due to the different government policy, business groups in both countries significantly differ in their size. 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). By contrast, the Taiwanese 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 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, business groups in these two countries also showed different evolution paths in terms of developing their capabilities and moving from OEM (Original Equipment Manufacture)-ODM (Original Design Manufacture)- OBM (Original Brand Manufacture) (Chu, 2009). While some Korean business groups like Samsung and LG were able to expand their operations and establish their own brands based on capabilities they achieved as OEM and ODM subcontractor, very few Taiwanese groups managed to build strong brands. Entering into the realm of OBM, the late-comer firms need to go through transformation of business models, for which they are required to make long-term investment in R&D and marketing capabilities while restructuring organizational structures and processes. Korean firms have successfully gone through this transformation towards becoming OBM, and this also resulted in difference in R&D expenditure / ratio between Korean and Taiwanese business groups, meaning that Korean groups have invested more in building internal innovation capabilities (Chu, 2009).

The business groups also 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 a limited access to diverse knowledge, which leads to rely more on external knowledge sourcing.

Based on the above argument, we hypothesize as follows:

Hypothesis: As compared to Taiwanese business groups (Jituanquiye), Korean business groups (Chaebol) are more likely to rely on internal knowledge creation and are less likely to engage in geographically dispersed co-inventorship.

METHODOLOGY AND EMPIRICAL ANALYSIS

Research Setting: the Electronics Industry

The electronics industry is an exceptional target for studying innovation capability catch-up in East Asia. Traditionally, the electronics industry has been a backbone of industrialization process in East Asian countries due to a massive expansion of international production by foreign electronics firms, from both Japan and other major advanced countries, combined with government industrial policy (Belderbos & Zou, 2006; Ernst & Guerrieri, 1998). To reflect this, East Asian countries became a home for Fortune 500 global companies such as Samsung Electronics (Korea), Hon Hai Precision Industry (Taiwan), Quanta Computer (Taiwan), Huawei (China) and so on. Patent data from USPTO also confirms this: industrial structure of Korea and Taiwan shows that the electronics industry has been a major sector in these economies (Figure 1). As a home for global companies such as Sony and Hitach, Japan also shows the similar pattern (Figure 2).

Figure 1 goes about here

Figure 2 goes about here

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 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). 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 are high-technology industries with active patenting activities (Penner-Hahn & Shaver, 2005), patent-related measures would provide strong insights into innovation activities in this industries. We extracted electronics patents using the technology classification suggested by Hall, Jaffe, and

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

Trajtenberg (2001). With this dataset, we identify patents that are connected to Korea and Taiwan. For the comparison purpose, we also identify patents that are connected to Japan. As the first Asian economy to industrialize, Japan was a more advanced economy, especially during the industrialization period of Asian countries (*The Economist*, 2012). Hence, we expect that it would present different case from Korea and Taiwan. 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. Furthermore, in order to determine the general level of global connectivity, we also compare country dispersion of inventors of the patents from two countries with the same measure for the patents from China, identified in the same way. Our study period is from 1980 to 2010.

Variables

Dependent variable. Following Hannigan, Cano-Kollmann, and Mudambi (2015), we construct a measure called *country dispersion of inventors*. 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 in order to measure how dispersed or concentrated the inventors are across countries.

Independent variable. *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.

Control variables. We include two different levels of control variables that could possibly influence the relationship between country dispersion of inventors and business groups, and therefore could confound our results. First, we include firm-level control variables. *Foreign MNE* is a dummy variable that takes 1 if the firm is international. *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, year dummy variable are included in the model.

Model and Econometric Approach

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

$$\text{Country Dispersion of inventors} = logit^{-1}(\beta_0 + \beta_1 \text{ Business group} + firm - level\ controls + patent - level\ controls + year\ dummy) + \varepsilon_{ijt}$$

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.

EMPIRICAL RESULTS

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 dispersion of inventors in Japanese patents throughout all the years followed by Korean patents. Taiwanese patents seem to show higher level of dispersion 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.

Table 1 goes about here

The low dispersion 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 country dispersion, which can reflect an increasing effort to source advanced knowledge in other countries to enhance the competitiveness. Moreover, as they develop fundamental technological capabilities within the industry over time, one could expect more active knowledge sourcing through co-inventorship based on their improved absorptive capacity (Cohen and Levinthal, 1990). However, this is not shown in our descriptive analysis and this pattern is quite different from the pattern observed for Chinese patents. Not only is the absolute value for country dispersion 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.

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.

Table 2 goes about here

The results from Generalized Linear Model (GLM) regressions are presented in Table 3. We employed a multiple regression approach to test our hypothesis in each country sample. Results from our baseline models for all three countries (Model 1) show that as consistent 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 for Korea and this may be due to their large knowledge pool so that they do not need to rely on external knowledge. With regards to other organizations, these organizations in Korea and Taiwan shows 'closedness' towards global innovation collaboration while the ones in Japan are more 'open'. Model 1 also shows that there is positive relationship between number of inventors and assignees in a focal patent and country dispersion of inventors.

Model 2 confirms our hypothesis that there is difference between Korean business group (*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. Similar to Korea, Japanese business groups (*Keiretsu*) are negatively correlated to country dispersion of inventors. 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 4. The results are quite similar to what we observed from Table 3 (for the full sample period).

Table 3 goes about here

Table 4 goes about here

DISCUSSION AND CONCLUSION

We began this paper by noting that connectivity to the global innovation system through co-inventorship or innovation collaboration has been recognized as important for innovation capability building. 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. Both Korea and Taiwan show a relatively low level of connectivity to global innovation system, when compared to China. One explanation could be that Korea and Taiwan focused strategically on emerging technologies (Lee & Lim, 2001; Lee, Lim & Song, 2005; Lee, 2013) which made them possible to develop new technologies based on indigenous knowledge without depending heavily on foreign knowledge. This could be why we observe limited connectivity to the global innovation system in their co-inventor networks.

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.

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.

Although we found that both countries share the low connectivity pattern as a whole country, we also found a stark difference among business groups in these countries. From the regression analysis, we can see 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 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). 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.

In addition, unlike most Taiwanese firms, Korean firms developed themselves from OEM to OBM and built strong R&D and marketing/branding capabilities during this transformation (Chu, 2009). With these capabilities, Korean groups also invested highly on establishing internal knowledge base, which could have led to more independent innovation effort without much international collaboration. In the same vein, as Taiwanese firms remained as subcontractors to foreign firms for a longer period of time, they could have been exposed to more opportunities for collaborating across borders in creating new knowledge. In other words, the development path that

Taiwanese business group firms went through led to more interdependent relations with foreign collaborators, which in turn could have led to more inclination to source knowledge abroad in terms of co-inventorship.

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). Not only that Japanese firms' desire to protect their intellectual property is very high, preventing them from engaged in alliances with foreign partners (*The Economist*, 2007). Rather, Japanese firms have strengthened the protection of their intellectual property through inter-*keiretsu* collaborations (Hu, 2012). Similar phenomenon is also observed in Korean firms. Chang (2006) 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).

Finally, we acknowledge that co-inventor network is not the only possible channel through which international knowledge sourcing could occur and that there are other forms of knowledge transfer mechanism that facilitate knowledge sourcing from abroad. 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. In 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 is not the only one route to successful innovation capability building and that there can be other routes to the successful catch-up. Focusing on emerging technologies and developing national human resource pool could be one way to achieve this. Both countries, in fact, have hugely invested in education system during the early years of industrialization, and that might be the main reason why they have succeed in catching up without relying on external knowledge significantly. Korea and Taiwan are well known to be one of the heavy investors in education, setting education as strategic policy, thus creating a large pool of skilled human resources (Guo, 2005, Sullivan, 1998). Reflecting this, statistics show that since the 1980s, the both government expenditure on education accounted for about 5 % of GDP (UNESCO, 2015; Mai & Shi, 2001).

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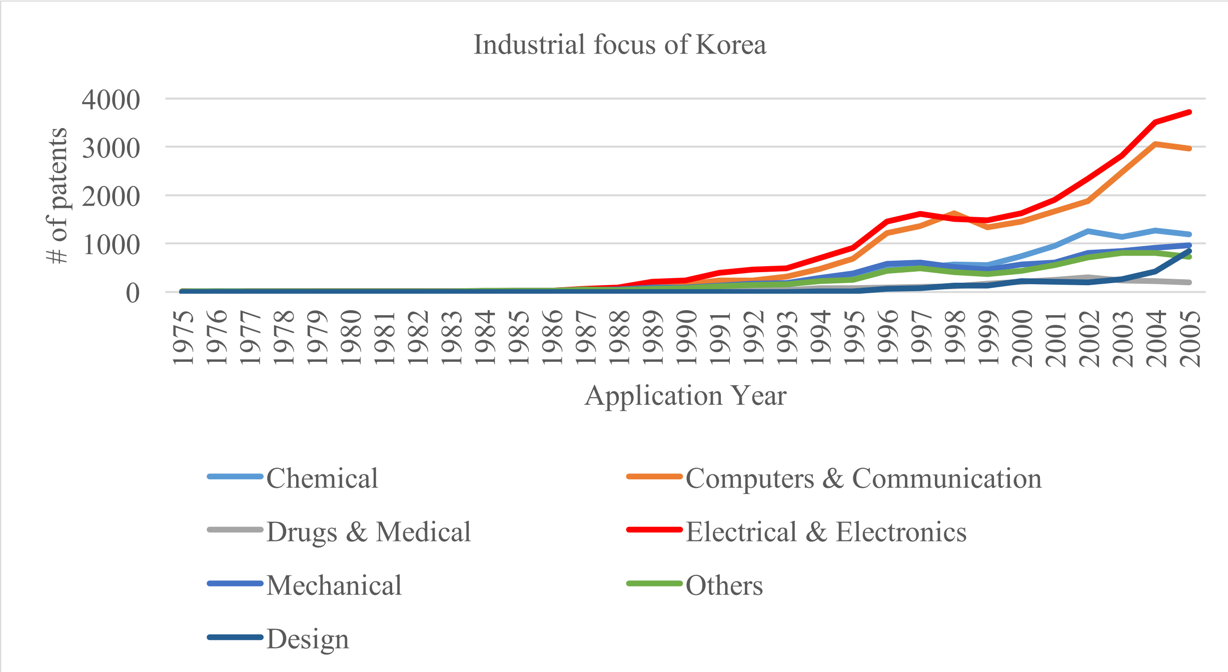
Figure 1. Industrial structure of Korea and Taiwan (1975-2005)



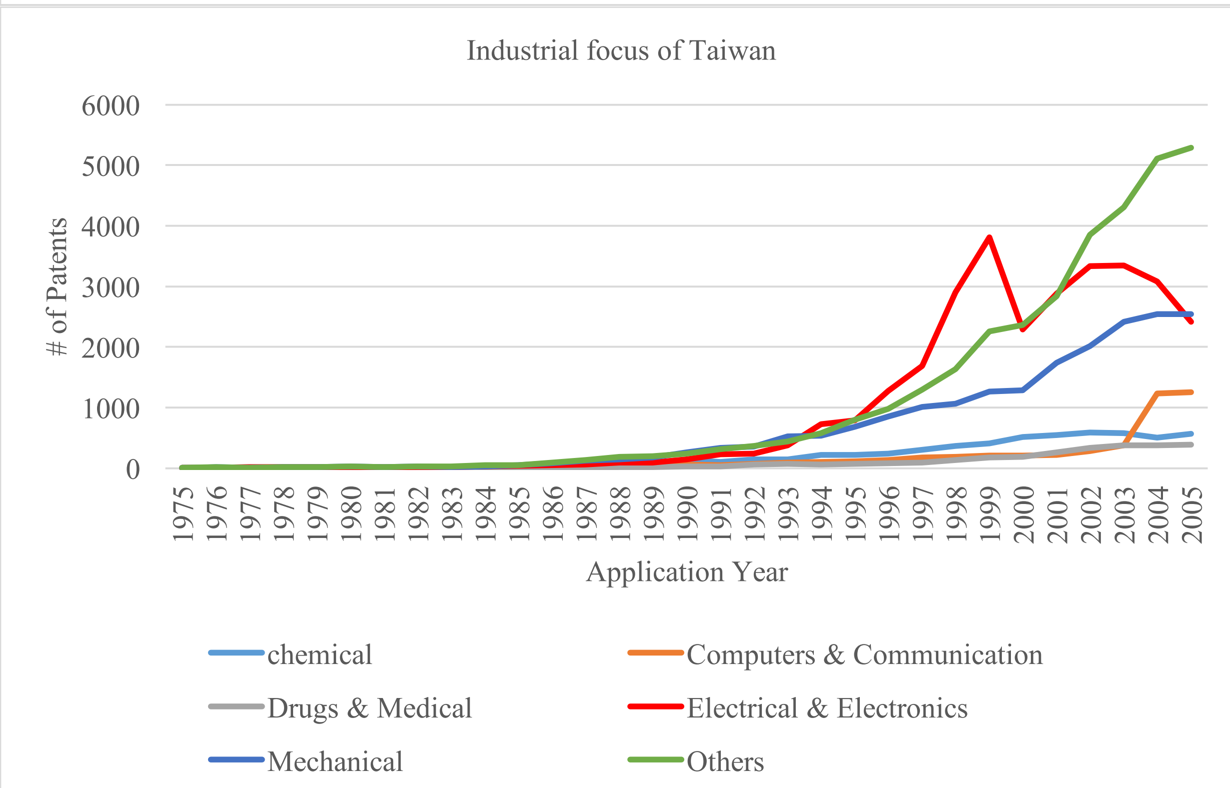


Table 1. Country dispersion of inventors in electronics industry

	Korea		Taiwan		Japan		China	
Year	Observations	Mean	Observations	Mean	Observations	Mean	Observations	Mean
1980-1989	182	0.045	267	0.023	24661	0.0029	64	0.130
1990-1999	6332	0.009	4045	0.016	58915	0.0064	235	0.173
2000-2009	20196	0.010	11125	0.030	92091	0.0081	6442	0.179
2010	33	0.013	32	0.027	69	0.0046	60	0.089
Total	26743	0.019	15469	0.024	175736	0.0055	6801	0.143

Table 2. Summary statistics and Pearson correlation

Variable	Mean	s.d.	1	2	3	4	5	6	7	8	9
1. Country dispersion	0.0102	0.0675	1.00								
2. Chaebol	0.1547	0.3616	-0.0417***	1.00							
3. Jituanquiye (Taiwanese group)	0.0394	0.1945	0.0808***	-0.0866***	1.00						
4. Keiretsu	0.4188	0.4934	-0.0759***	-0.3629***	-0.1719***	1.00					
5. Foreign MNE	0.0285	0.1665	0.2443***	-0.0636***	-0.0138***	-0.0641***	1.00				
6. Other organization	0.0192	0.1371	0.0435***	-0.0598***	-0.0283***	-0.1184***	-0.0198***	1.00			
7. Leader	0.2572	0.4371	-0.0603***	0.3417***	-0.1192***	0.1115***	-0.0571***	-0.0823***	1.00		
8. Number of inventors	2.4809	1.7847	0.1051***	-0.0483***	-0.0213***	0.1061***	0.0149***	0.0662***	0.0085***	1.00	
9. Number of assignees	1.0205	0.3220	0.0612***	-0.0207**	-0.0064***	0.1115***	0.0218***	0.035***	0.0012	0.1914***	1.00

Table 3. Regression Results: (1980-2010)

	Korea		Taiwan		Japan	
	(1)	(2)	(1)	(2)	(1)	(2)
VARIABLES	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*
Main effect						
Business group		-2.2351***		0.7355***		-0.6088***
		[-14.20]		[9.53]		[-10.45]
Controls						
Foreign MNE	3.1816***	2.0155***	1.7410***	2.0899***	3.3805***	3.1243***
	[30.65]	[16.79]	[16.93]	[19.08]	[69.21]	[57.66]
Other_org	0.8816***	-0.3523**	-0.7554**	-0.3714**	1.9098***	1.6226**
	[6.78]	[-2.52]	[-4.43]	[-2.11]	[12.96]	[10.89]
Leader	-1.1131***	-0.0138	-0.7880	-0.7464	-0.4688***	-0.2975***
	[-9.28]	[-14.20]	[-1.28]	[-1.15]	[-5.96]	[-3.73]
Inventor_num	0.2804***	0.2603***	0.2856***	0.2662***	0.2165***	0.2254***
	[17.07]	[15.13]	[18.23]	[17.05]	[28.35]	[28.58]
Assignee_num	0.5014***	0.6598***	0.6665***	0.6226***	0.4207***	0.4294***
	[2.87]	[5.48]	[4.70]	[4.54]	[13.43]	[13.23]
Year Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	28,464	28,464	17,093	17,093	113,340	113,340
Log pseudolikelihood	-1003.99	-1047.99	-1663.95	-1641.17	-3765.04	-3739.34

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

Table 4. Regression Results: Sub-sample (2000-2010)

	Korea		Taiwan		Japan	
	(1)	(2)	(1)	(2)	(1)	(2)
VARIABLES	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*	DV: *Dispersion*
Main effect						
Business group		-1.7741***		0.9850***		-0.5786***
		[-10.28]		[11.45]		[-9.07]
Controls						
Foreign MNE	3.0926***	2.1473***	1.7463***	2.2642***	3.3207***	3.0812***
	[26.85]	[15.10]	[15.33]	[18.05]	[62.73]	[52.44]
Other_org	0.8003***	-0.0791	-0.9551***	-0.4145+	1.7674***	1.4938***
	[5.12]	[-1.06]	[-4.66]	[-1.96]	[10.25]	[8.53]
Leader	-1.3120***	-0.5055***	-0.7868	-0.8222	-0.5412***	-0.3671***
	[-9.19]	[-2.88]	[-1.20]	[-1.20]	[-6.05]	[-4.02]
Inventor_num	0.2535***	0.2364***	0.2515***	0.2208***	0.2491***	0.2572***
	[13.73]	[12.40]	[15.01]	[13.27]	[28.58]	[27.85]
Assignee_num	0.7734***	0.8254***	0.6465***	0.6269***	0.3923***	0.3995***
	[4.40]	[5.84]	[3.96]	[4.06]	[12.28]	[12.03]
Year Dummies	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	20,513	20,513	11,564	11,564	92,319	92,319
Log pseudolikelihood	-790.16	-763.92	-1277.78	-1245.0	-3118.35	-3098.28

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