INTERNATIONAL KNOWLEDGE SOURCING AND NATIONAL TECHNOLOGICAL DEVELOPMENT WHEN THE INTERNATIONALIZATION OF R&D IS HISTORICALLY WEAK: A STUDY OF THE KOREAN CASE.

by

SE HO CHO

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ABSTRACT OF THE DISSERTATION

International knowledge sourcing and national technological development when the internationalization of R&D is historically weak: A study of the Korean case.

By SE HO CHO

Dissertation Director:

Dr. John Cantwell

The purpose of this dissertation is to investigate the international knowledge sourcing of firms located in a home country with weak internationalization of R&D. in the international business literature, much attention has been devoted to analyzing the role of subsidiaries in foreign countries for knowledge transfer and exchange in a multinational corporation (MNC) internal network. However, South Korea has developed strong technological capabilities in firms based in the home country through several other channels of international knowledge sourcing, rather than through the R&D activities of subsidiaries of these firms abroad. Thus, studying the determinants of the knowledge sourcing of firms in Korea can provide us with some new perspectives on knowledge sourcing behavior, and so enrich the literature on knowledge sourcing and international business, by shedding light on a broader set of issues in cross-border knowledge sourcing.

This research examines 1) the impact of Korea's comparative technological development and 2) the effects of the relative openness of an industry, on the knowledge sourcing behavior of firms in Korea, using patent citation data derived from the USPTO patent database held at Rutgers University. We find that Korea's comparative technological development influences firms' international knowledge sourcing, its degree of technological field dispersion and its cross-country geography. We also find that international connectedness associated with the relative openness of an industry plays an important role in international knowledge sourcing both within and between industry in the home country, by facilitating access to knowledge in foreign countries, and by accumulating stronger technological capabilities in that are more open industries. The findings and issues discussed in this dissertation may be applicable in the development of public policies in many emerging market countries to boost domestic capacity for international knowledge sourcing in order to better catch-up with the advanced technologies that are available in selected locations around the world.

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1. Introduction

Knowledge sourcing is critical to inventing and developing new technology. When a new technology comes up, it starts from the combination and use of several existing streams of knowledge. Technology complexity and the dispersion of technological knowledge in the world requires firms to source knowledge internationally. Each country has some distinct technological advantages in specific industries. Small countries in particular, such as many Asian and European countries, cannot source all the technological knowledge they need from their home country because of their limited size and resources. It is impossible for even a large country to have a strong position in all kinds of technologies and industries. From this standpoint, international knowledge sourcing becomes increasingly common and necessary to continuously upgrade and develop technology in any place.

The technological activities of firms from many western European countries have been decentralized to foreign subsidiaries at least since 1960s (Cantwell, 1995, Cantwell & Kosmopoulou, 2002). Therefore, more heterarchical structures have been developing and evolving within multinational corporations (MNCs) (Hedlund, 1986). Previous studies in international knowledge sourcing have mainly stressed the relationship between parent firm and its subsidiaries in foreign countries, and the role of subsidiaries in foreign countries in the MNC network (Frost, 2001; Song et al, 2011; Cantwell & Mudambi, 2011). In fact, MNCs from some European countries such as the Netherlands, Sweden, Switzerland, the United Kingdom and Belgium have developed around half of their technology in foreign locations, so the role of subsidiaries in foreign countries are critical in knowledge development and flows among the leading firms in those countries.

However, there are some other countries that have developed strong technological capabilities primarily through other modes of international knowledge sourcing rather than through the technological activities of subsidiaries in foreign countries or MNC networks. Japan has created and accumulated strong technological knowledge with a relative lack of internationalization of the R&D. More recently, South Korea has also developed remarkable technological capabilities relying mainly on channels other than the technological activities of subsidiaries in foreign countries (see Table 1). Therefore, analyzing the knowledge sourcing behavior of Korean firms at home can potentially enrich and provide some balance to the literature on knowledge sourcing and international business, by bringing a wider perspective on the nature of international knowledge sourcing.

Table 1. The share of US patents of firms attributable to research in the home country, 1983-2010 (%)

Country	1983-1989	1990-1996	1997-2003	2004-2010	Total
South Korea	99.59	97.52	96.67	96.36	96.54
Japan	99.54	98.76	96.84	96.16	97.36
Taiwan	93.36	95.80	92.72	87.90	89.71

South Korea is one of the most advanced emerging economies and its economy has been developed successfully over the last few decades. South Korea was one of the poorest countries in the world immediately after the Korean War (1950-53). Since then, Korea has rapidly industrialized and achieved remarkable technological development over the last 60 years. Between 1962 and 1994, Korea had an average 10 percent growth in real GDP annually. Korea’s GDP per capita has increased rapidly from US $944 in the early 1960s to US $25,458 in 2016[1]. Although South Korea is a small country in terms of geographical size, it has now become the world's 14th largest economy[2] based on GDP PPP.

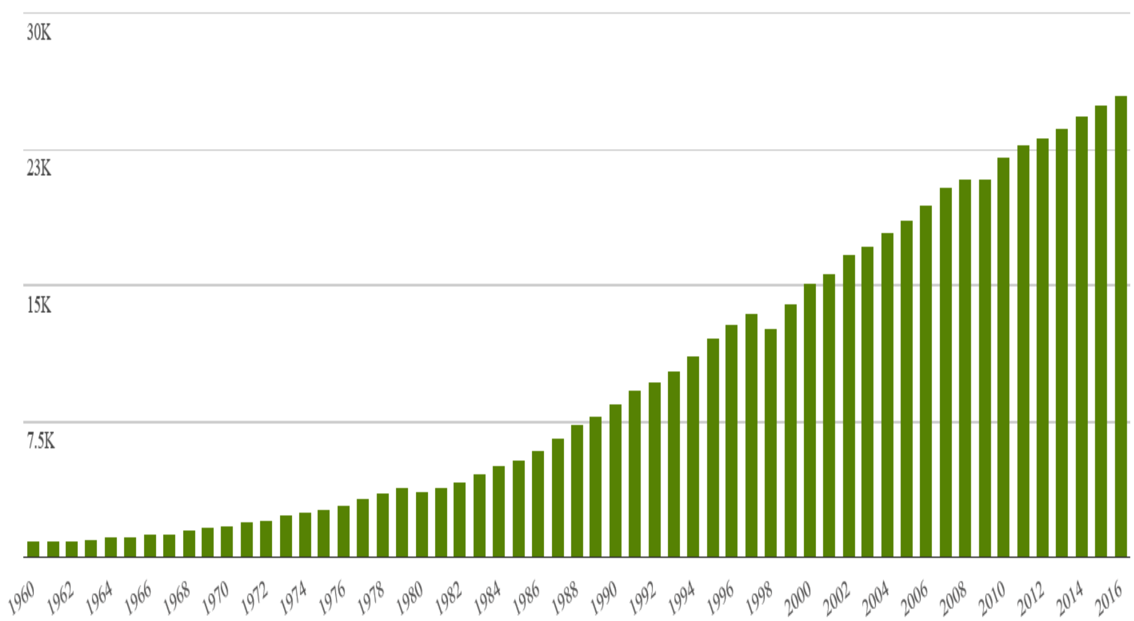

Figure 1. GDP per Capita (constant 2010 US$, Source: World Bank)

Although one of reasons of Korean economic development may have been the Korean government's support of industries during 1960s - 1970s, more important factors in the longer term are that Korean firms developed their own technological capabilities through partnership and looser forms of cooperative arrangement, such as licensing or original equipment manufacturing with foreign MNCs during 1980s. In this process, Korean firms have engaged in steadily more technological activities and have built more

[1] World Development Indicators by World Bank, 2016 (Constant 2010 US$)
[2] World Bank, 2014

capabilities to compete with domestic and foreign competitors. Along with its significant economic growth, South Korea has developed and come to possess significant capabilities in the generation of technological knowledge. According to the USPTO patent data base, the total number of patents developed by first-named Korean-resident inventors by 2015 is 152,835. This is sixth place in terms of the number of patents granted, following the US, Japan, Germany, United Kingdom, and France[3].

Not many patents were developed in Korea until 1970s and there has been an exponential growth of Korean patents since the 1980s. While Korean firms had few technological capabilities until the 1970s they mostly focused on simple production and assembly in light industries. Subsequently, they moved into heavy industries and began to invest and develop relevant technologies during the 1980s. As Korean firms became more competitive in several heavy industries from the 1990s onwards, their activities in R&D moved from the simple introduction and adoption of foreign technologies to the in-house development of their own technologies, and so they have registered a large number of patents over the last 30 years. Although small Korean firms have also invented and patented, R&D and technological activities in Korea were driven mainly by large firms because these activities required a huge amount of investment which essentially only the large firms could afford. Based in part on their new capabilities in R&D and technological development, several large Korean firms, such as Samsung, Hundai, Posco, and LG, became MNCs and their technological activities have enabled them to produce many world-class products.

How did South Korea develop such impressive technological capabilities by world standards? Historically, Korean firms have had a low level of international innovative

[3] A Patent Technology Monitoring Team Report, USPTO 2015

activities, but the majority of technological development has been located at home. As late as 2010, around 97% of the technological activities of Korean firms were conducted in the home country (see Table 1). Unlike the largest firms of European countries, the internationalization of R&D activities through foreign subsidiaries has remained very low in South Korea, when compared to other countries at a similar level of development. Moreover, South Korea did not have a high internal level of technological knowledge in the past. Even in the absence an extensive foreign subsidiary network and a lack of indigenous technological knowledge, South Korea has successfully developed technological capabilities in the home country by means of sourcing from abroad most of the antecedent knowledge required for Korean innovation. This has been possible through various channels for international connectedness and through modes of international knowledge sourcing other than intra-firm relationships.

South Korea has been quite highly economically connected with a variety of foreign countries during its recent industrialization process. South Korea and Japan have been geographically and historically connected each other because of geographical and cultural proximity and due to Japanese colonial rule for 35 years. Therefore, many Korean firms have applied several Japanese economic systems even after South Korea gained independence from Japan. In the catch-up process during the 1950s - 1970s, the United States assisted South Korea in reconstructing and developing its economy, so many parts of the Korean economy are connected to the US economy. Moreover, Korean firms have had international connections through several modes such as arm’s length trade, and in particular through supply chain linkages entailing original equipment manufacturer (OEM), or original design manufacturer (ODM) agreements with firms in many foreign countries. In this process, Korean firms were able to reverse engineer some kinds of knowledge that originated in certain foreign countries, and to take the opportunity to learn about foreign technological knowledge.

Since Korean firms have used a variety of channels for international knowledge transfer and acquisition and these channels have become interconnected with one another, defining and examining these channels individually or separately is of limited value. Therefore, we are more concerned here with the overall consequences of combining diverse channels at an aggregate level, rather than identifying the significance of specific underlying channels for knowledge transmission. By investigating Korean firms' knowledge sourcing through any potential organizational channel, we can analyze how Korean firm's knowledge sourcing has been either similar to or different from the sourcing of other countries whose firms have obtained knowledge via the geographic dispersion of technological activities within the MNC.

Moreover, South Korea has a dualistic industrial structure. The more dynamic are the "outer" focused industries, while others are essentially "inner" dependent industries. Some industries have been continuously developed by sustaining more connections to foreign countries, and these can be termed the outer-focused industries. Instead, other industries have been regulated and protected from competition in both the domestic and foreign domains. Thus, these industries are more domestically oriented, and they can be termed inner-dependent industries. Korea's dual industrial structure has been formed over time through the rapid growth of the outer-focused industries and the protection of inner-dependent industries.

The form of international connectedness that emerged in the Korean form of industrialization, and the dualistic structure of Korean industries, offer an interesting context in which to investigate knowledge sourcing behavior. Many other studies in other national contexts have focused on parent-subsidiary relationships as influences upon knowledge sourcing. However, parent-subsidiary knowledge exchange has not been critical in the Korean case. In the Korean case, we can observe and examine knowledge sourcing behavior in a more general setting that has allowed for a diversity of channels at an aggregate level. Therefore, the Korean context has entailed a wider spectrum of knowledge sourcing channels, and so this raises a broader set of issues about knowledge sourcing.

Although MNC-parents' knowledge sourcing behaviors are studied by Song and Shin in their 2008 JIBS paper, they only analyzed the MNC-parents' knowledge sourcing from the host countries in which their R&D subsidiaries exist. When enough R&D is conducted by subsidiaries with competence-creating mandates, then this may help their MNC-parents in the home country to source knowledge from the relevant host countries through these subsidiaries (Cantwell & Mudambi, 2005). However, if a firm's R&D activities are essentially concentrated in the home country as in the case of Korea, it is not possible for firms to actively use competence-creating subsidiaries in foreign countries as mediators through which to obtain knowledge from foreign countries, as there are too few such subsidiaries. In spite of the practical importance of knowledge sourcing by firms located in home countries with a weak internationalization of R&D, to the best of my knowledge, there has been a lack of research on this topic. Studying knowledge sourcing by firms located in the home country with weak internationalization of R&D still remains little studied. Thus, we believe it is meaningful to investigate the conditions and circumstances that influence the knowledge sourcing of firms located in Korea, which has had a weak internationalization of R&D.

The dissertation proceeds as follows. In section 2, we review literature on international knowledge sourcing. Section 3 explains the organization of data including the operationalization of key variables and the relevant structure of patent data, and presents some descriptive statistics of citing patents and cited patents invented in South Korea. In section 4, we analyze the relationship between changes in the comparative technological development of Korea and Korean firms' international knowledge sourcing as Study 1. One of the most interesting points about Korea is that Korea has successfully caught up with advanced countries in terms of technological development. In the process of rapid catch-up, we suggest that Korea has displayed some distinctive features. Within the context of technological catch-up in Korea, it is interesting to investigate the impacts of Korea's technological development on Korean firms' international knowledge sourcing behavior. In section 5, we consider the relative openness of an industry in the context of the dualistic structure of the Korean economy in Study 2. Although the impacts of the national technological development and changes on Korean firms' international knowledge sourcing behavior are investigated in Study 1, only national level factors are considered. The dualistic structure of Korean industries is a critical feature and this needs to be considered as well in its effects on Korean firms' knowledge sourcing behavior. Studying the significant differences between the Outer-focused industry (more internationally connected) and Inner-dependent industry (more domestically oriented) industries in their patterns of international knowledge sourcing is important to better understand the relationship between Korean industries also in local knowledge sourcing locally. Finally, section 6 concludes with a review of the main findings, contributions and the prospects for future research.

2. Literature review

Knowledge is a critical resource for firms' competitive advantage (Quinn, 1992; Teece, 1998), so firms have consistently created and developed many kinds of knowledge. Thus, firms play an important role in the process of knowledge creation and they act as repositories of the knowledge source (Cantwell and Fai, 1999).

Historically, literature on FDI had suggested that MNCs use FDI to exploit and adapt their home-country based knowledge to foreign countries (Hymer, 1976; Caves, 1971). Accordingly, MNCs develop their technology in their home country, and foreign R&D affiliates adapt their parent firms' technology to local customers' needs in the host countries through FDI. In recent years, however, innovative activities have increasingly become geographically dispersed through the international network of MNCs (Cantwell, 1995; Ernst, 2002). To access and obtain technological knowledge from various locations, MNCs have established global networks (Bartlett & Ghoshal, 1999; Hedlund, 1986). MNCs have engaged in technology-seeking FDI through R&D subsidiaries in foreign countries. By doing so, they can develop competitive advantages by identifying and integrating the knowledge embedded in the host country with capabilities inherited from the home country (Almeida, Song, and Grant, 2002). Complementary knowledge to that existing in home base is developed and acquired by the foreign R&D subunits (Asakawa, 2001; Florida, 1997; Shan & Song, 1997). Therefore, recent research has increasingly focused on the localization of the knowledge sources by foreign subunits (Almeida, 1996; Almeida & Phene, 2004; Asakawa, 2001; Cantwell & Mudambi, 2011; Frost, 2001; Phene & Almeida, 2008; Song et al., 2011; Tallman & Phene, 2007).

Early empirical studies tracked technology-seeking FDI. Kogut and Chang (1991) analyzed Japanese firms' direct investment into the US, and showed how this is connected to sectoral R&D intensity in the US. They found that Japanese firms used FDI through joint ventures to access and share US technological capabilities. Some other studies of Japanese MNCs have also shown evidence that Japanese R&D units are mainly located around important US research centers to access and obtain new technological knowledge (Westney,1993; Florida and Kenney, 1994). Cantwell (1992) found that MNCs set up their foreign subunits in the areas of greatest technological expertise in the UK.

Shan and Song (1997) investigated foreign MNCs' motivation for direct investment in the biotechnology industry of the US. They found that MNCs are more likely to source country-specific, firm-embedded technological advantages in the US. Almeida (1996) investigated technological knowledge sourcing of MNCs' foreign subunits in the US semiconductor industry. He found that MNCs' foreign subunits even more actively source local knowledge than similar US firms in the same region. According to his argument, MNCs use FDI to obtain location-specific knowledge and offset a home country's technological weaknesses. Almeida et al. (2002) discuss the relative efficiency of alternative modes of technological knowledge transfer between countries. The empirical results from patent data of firms in the semiconductor industry show that internal mechanisms within MNCs can be superior to alliances and markets in terms of knowledge transfer.

More recent studies have been directed towards understanding the effects of foreign subsidiaries' capabilities and positions on knowledge sourcing. Asakawa (2001) investigated the role of subsidiaries in foreign countries on knowledge creation within the

MNCs' internal network. He emphasized the importance of reconciliation between subsidiary autonomy and smooth knowledge transfer in the MNC internal network. Frost (2001) argued that the degree of foreign subsidiaries' technological capabilities can influence the geographic origins of a knowledge source. If foreign subsidiaries have weak technological capabilities, they are more likely to source knowledge from parent firms in the home country. Instead, foreign subsidiaries with strong technological capabilities tend to source knowledge from the host countries in which they are located. Cantwell and Mudambi (2005) presented competence-creating affiliate mandates as being influenced by the scope for knowledge sourcing from the host country, the position of an affiliate in its MNC-internal network, and other locational factors in the host country. Almeida and Phene (2004) analyzed the influence of external knowledge on the innovation capability of subsidiaries according to the availability of such external knowledge sources. They suggested three effects that depend upon the MNC's technological richness, the host country's technological diversity, and the extent of local knowledge linkages that the subsidiary has in the host country. Phene and Almeida (2008) studied the importance of knowledge sourcing from the host country for a subsidiary's technological innovation. Moreover, they suggested the subsidiary's sourcing capability and combinative capability are critical for its technological innovation. In a similar vein, Song et al. (2011) explained the knowledge sourcing behaviors of foreign subsidiaries with two perspectives, own technological capabilities and embeddedness in the host country. They found that both foreign subsidiaries' technological capabilities and embeddedness in the local scientific and engineering communities influence foreign subsidiaries; knowledge sourcing from host countries. Cantwell and Mudambi (2011) analyzed foreign subsidiaries' knowledge sourcing behaviors based on the relationship between dominant firms in a local industry and foreign subsidiaries. With the concept of *physical attraction*, they argued that as the physical attraction of dominant firms in a local industry increases, foreign subsidiaries can gain fewer benefits from local knowledge spillovers if they are outsiders with weaker connections to others. In contrast, if foreign subsidiaries are insiders with stronger connections to others, they can access more local knowledge. With reference to 92 published papers between 1996 and 2009, Michailove and Mustaffa (2012) reviewed and classified earlier studies on subsidiary knowledge flows in MNCs into four categories; outcomes of knowledge flows, knowledge characteristics, the actors involved in knowledge flows, and relationships between these actors.

As we can see from this review of recent literature on knowledge sourcing, most studies have concentrated on knowledge sourcing through foreign subsidiaries. Although subsidiaries in foreign countries have become more important for the creation of new technology, there are still many firms that rely on foreign subsidiaries primarily for the purpose of exploiting the firms' home base knowledge. Indeed, firms are less likely to set up advanced R&D subsidiaries in foreign countries when they have absolute technological advantages (Chung & Alcacer, 2002). Moreover, firms may be concerned over the negative impact of knowledge spillovers or leakages. They may hesitate to locate their foreign R&D centers in a host country due to fears of knowledge leakage to local rivals (Flyer & Shaver, 2003).

Openness to external knowledge sources is beneficial for innovation (Chesbrough, 2003; Laursen & Salter, 2006; Leiponen & Helfat, 2010) as it facilitates connections to external knowledge. The potential value of external knowledge connectedness is to stimulate creativity and to accelerate the quality of the innovations (Powell,1998). The connectedness with external knowledge resources can also increase a firm's accessibility to technological knowledge located outside the firm (Leiponen & Helfat, 2010; Niosi, 1999). Since knowledge depends upon location specific factors (Cantwell, 1989), international connections are needed in order to achieve the most suitable forms of knowledge sourcing to access globally dispersed knowledge. Firms and industries can become more internationally connected by expanding their business in foreign countries through exporting (Branstetter, 2001; Salomon and Shaver, 2005) or by receiving investment from foreign actors as occurs in the case of inward FDI (Sinani & Meyer, 2004).

3. Data overview of structure & operationalization

We are going to use (cited) patent data to investigate the knowledge sourcing of firms. Thus, in this chapter, we will first define key variables that will be used in the studies. Second, we will discuss why we use the United States Patent and Trademark Office (USPTO) patent data to analyze knowledge sourcing. Finally, we will provide some summary descriptions of our dataset.

3.1. Key concepts

In this section, definitions and of key concepts that will be developed as variables of hypotheses in three studies are described.

Knowledge sourcing and international knowledge sourcing

Knowledge sourcing is a key concept in this dissertation. When firms create and update technologies, they always draw upon existing technologies as sources of knowledge. New technology is not created in a vacuum, but in a cumulative way by combining existing technological knowledge. Therefore, sourcing the required knowledge antecedents is a critical factor for new knowledge creation and development. In this dissertation, knowledge sourcing is defined as the access to and exploitation of prior technological knowledge which is potentially patentable, and international knowledge sourcing refers to the earlier patented technological knowledge invented in foreign countries on which the development of new technological knowledge in Korea draws.

National technological development

We define national technological development as the accumulation of the knowledge and technologies that are needed to enable the main agents of technological development such as firms, individuals, universities and research centers to adapt, improve and create technology (Lall, 1992; Bell & Pavitt, 1995). The level of a country's technological development can be measured by the ratio of the total number of patents invented in a country to the total number of patents invented in the world during the same period. See the section on variables and measures in Study 1 for more details.

Openness of an industry (international connectedness)

An industry can be more internationally connected when it is more open to influences from the rest of the world. In this study, the openness of an industry is defined as how much an industry is economically connected to foreign countries. International trade and international investment are the two most important ways in which an industry can become more internationally connected. In the case of Korea, exporting is more dominant than importing, and inward FDI plays a greater role than does outward FDI. Thus, export intensity and inward FDI will be used as the main indicators of openness for an industry. For inward FDI, we use the scale of FDI relative to the size of local industry, rather than the absolute size of inward FDI. See the section on variables and measures in Study 2 for more details.

Intra-field knowledge sourcing and inter-field knowledge sourcing

The intra- vs. inter-field distinction is based on a comparison of the classifications of citing and cited patents. Inter-field knowledge sourcing occurs when the technological field classifications of these patents differ. Intra-field knowledge sourcing means that the primary classifications of these patents are in the same technological field. For instance, when sourcing existing knowledge in the chemical fields to develop new chemical technology, we have intra-field technology sourcing. Nowadays, as technology becomes more complex, the share of inter-field knowledge sourcing has been rising.

3.2. Patent data

For the studies in this dissertation, firms' technological activities should be traced and analyzed. The major parts of the studies are based on firms' technological development and their technological knowledge sourcing. Patents can be valid measures of a firm's innovative success and technological strength (Narin, Noma, & Perry, 1987). Patent data provide valuable information such as the location, and the technical fields of inventions, and cited patents may span a very long-time period, so these data are useful to trace technological knowledge flows and sourcing across industries and countries.

Patent citations may have some limitations in capturing accurately knowledge flows, because patent citations are added by patent examiners as well as by patent inventors (Alcacer & Gittelman, 2006). However, studies through direct surveys of patent inventors show that patent citation data has a high correlation with actual knowledge flow (Jaffe & Trajtenberg, 2002). Moreover, several previous studies have used patent citations as indicators of knowledge sourcing (Almeida, 1996; Song & Shin 2008; Cantwell & Mudambi, 2011). Although tracing knowledge flows is not easy empirically, patent citations show how a trail of new knowledge development has led up to existing knowledge (Singh, 2005). Therefore, despite their limitations, we believe that the patent citation data are one of the best proxy measures of knowledge flows for empirical research.

The USPTO patent data are the most appropriate for our studies for three major reasons. First, the USPTO provides a better guide to international knowledge sourcing than does Korean Intellectual Property Office (KIPO). Indeed, patent citations from KIPO are generally biased by their focus on Korean firms and Korean territory, since the majority of the patents issued are registered by Korean firms and there are few patents granted to foreign firms. However, the USPTO reflects patenting activities from origins not only the US but from all over the world even if the patent office is located in the United States. Therefore, this provides a better international comparison, and citations from a much broader pool. According to reports by the USPTO patent technology monitoring team, from 1963 and 2015, the USPTO has granted a total of 6,122,266 patents to assignees across the world. Currently 55% of the patents come from the US and the other 45% are from foreign countries. Since the USPTO also imposes common screening and legal procedures on patent applicants from all over the world, the information of patent citations relies on a common benchmark or standard. A second reason why we choose the USPTO is that it is more comprehensive and historically consistent. The patent data of the USPTO provides a sophisticated technological classification and a long history of cited patents. Since my studies are related to knowledge flows and sourcing between countries and technological fields, a more comprehensive and consistent set of data over long term periods is highly advantageous. Finally, we tend to capture a better quality of innovative activities by using the USPTO system rather than we would through the KIPO. Like firms from other countries, Korean firms first apply for a patent at the KIPO and then secondly at the USPTO. This means the patents that are applied and granted in the USPTO have already passed a first screening process through the KIPO. Moreover, the US has a stricter pre-patenting screening policy than does the KIPO. By using USPTO patent data, we can eliminate some very low quality technological activities that play little role in firms' technological innovation. Thus, it helps that we study Korean firms' technological activities through analyzing relatively higher quality patents.

3.3. Descriptive statistics of citing patents invented in South Korea and their cited patents

The main purpose of this dissertation research is to investigate Korean firms' knowledge sourcing behavior. In order to measure knowledge sourcing, patent citations are used, and the unit of analysis is a pair of citing and cited patents, that considered at the patent level. The sources of the patent data are from Dr. John Cantwell's the US patent database, which was originally collected from the USPTO patent database.

We collected all the citing patents developed by inventors located in South Korea between 1984 and 2013. The total number of potentially citing patents by firms is 107,846. For each of these 107,846 citing patents, we obtained the information on the patent grant year, the location of the first named inventor, the name of the assignees (usually the name of a firm), and the US patent class and sub-class of its technological area. By matching the information about location of the first inventor with the identity of the assignees, we found that 105,250 patents were developed in Korea by Korean-owned firms.

Using the names of the Korean firms listed as assignees on the patents, the ultimate ownership of patents was confirmed and matched to their parent company name. By using the information from ‘Who Owns Whom’ and Data Analysis, Retrieval and Transfer system (DART) of Financial Supervisory Service, we manually mapped out all affiliates of Korean firms and confirmed which patents belong to each corporate group. In the next step, we extracted all the 745,349 cited patents referenced by the citing patents to trace their knowledge sourcing. Similarly, as was done with the citing patent data, we extracted information on the cited patent grant year, the location of the first inventor, the name of assignees, and the US patent class and sub-class of the 745,349 cited patents.

For the technological fields of patents, we used the primary classifications of the US patent class system, but they need to be aggregated into common fields of technological activity. In the USPTO system, the primary field of technological activity of each patent is categorized into around 400 classes, each of which may have up to 999 sub-classes. The patent class system is designed for the purposes of the patent examiners in the USPTO. Identifying similar inventions in some areas requires more subdivisions than others because their objective is to look at the technical details of an invention. However, this categorization is too specific for our research. Our objective is look at patents more from the downstream side of how the underlying knowledge comes to be used in productive processes. Thus, classes need to be grouped into common technological fields. Therefore, previous studies have regrouped the categories of the US patent class system into 56 technological fields (Cantwell & Andersen, 1996; Cantwell & Janne, 1999; Cantwell & Piscitello, 2015) (See Table 2). This 56 technological field classification is appropriate from the perspective of the areas of knowledge recognized by firms or industries as opposed to the perspective of patent examiners.

Table 2. Technological fields: correspondence with US patent classes

Tech. Field	*US Patent Class*	*Tech. Field*	*US Patent Class*
1	127, 131, 426	29	48, 91, 92, 110, 122, 126, 137, 165, 184, 185, 188, 192, 237, 239, 251, 303, 415–418, 431, 432
2	201, 203	30	235, 400
3	423	31	60
4	71	32	376, 976
5	23, 51, 55, 62, 134. 156, 204, 210, 260, 427, 432, 518	33	178, 179, 329, 332, 367, 370, 375, 379, 455
6	430	34	340, 341, 382
7	106, 252, 512	35	342, 343
8	422	36	84, 181, 358, 381,
9	260. 520-528	37	313–315, 362
10	8	38	174, 200, 307, 308, 323, 328, 330, 331, 333–339, 361, 363, 372, 439, 505
11	260, 530, 534, 536, 540, 544, 546, 548, 549, 552, 556, 560, 562, 564, 568, 570, 930	39	62, 136, 204, 219, 236, 290, 310, 318, 320, 322, 361, 373, 388, 392, 429, 437
12	424, 435, 436, 514, 800, 935	40	307, 357
13	29, 75, 148, 164, 228, 419, 420	41	235, 360, 364, 365, 369, 71, 377, 902
14	3, 4, 7, 10, 16, 24, 27, 30, 49, 63, 70, 108, 109, 124, 132, 135, 138, 150, 160, 182, 90, 206, 211, 215, 220, 232, 248, 256, 267, 272, 279, 285, 292, 312, 383, 403, 411, 464, 623	42	123
15	99, 127, 131	43	180, 296
16	34, 51, 55, 68, 118, 134, 156, 159, 196, 202, 209, 210, 261, 366, 422, 494, 502, 503	44	244

17	59, 72, 76, 81, 82, 83,163, 164, 173, 225, 228, 234, 266, 269, 308, 384, 407-409, 413, 474	45	114, 440, 441
18	53, 162, 229, 493	46	104, 105, 213, 238, 246
19	65, 241, 249	47	191, 280, 293, 295, 298, 301, 305
20	186, 187, 193, 198, 212, 224, 226, 242, 254, 258, 271, 294, 402, 406, 410, 414, 901	48	2, 36, 245, 289, 450
21	56, 11, 130, 172, 278, 460	49	152, 264
22	37, 171, 404	50	52, 65, 125, 215, 241,428, 501
23	166, 175, 299	51	44, 208, 585,
24	445	52	354, 355
25	12, 19, 26, 28, 38, 57, 66, 69, 87, 112, 139, 223	53	33, 73, 74, 128, 177, 187, 235, 250, 324, 346, 350–353, 356, 368, 374, 378, 433, 475, 600,604, 606
26	101, 199, 270, 276, 281-283, 412, 462	54	5, 217, 297
27	142, 144, 145	55	149
28	15, 30, 79, 98, 100, 116,133, 140, 141, 147,157, 169, 194, 221, 222, 227, 254, 277, 291, 300, 401, 425, 453	56	6, 14, 17, 40, 42, 43, 47, 54, 86, 89, 102, 114, 119, 168, 231, 244, 273, 380, 404, 405, 434, 446, 449, 452

Source: Cantwell, J., & Piscitello, L. (2015). New competence creation in multinational company subunits: The role of international knowledge. *The World Economy*, 38(2), 231-254.

We apply this classification of patents into 56 technological fields for both the citing and the cited patents in our data set. The description of each technological field and numbers of citing and cited patents of each field by firms in South Korea is shown in the Table 3.

Table 3. List of the 56 technological fields and technological distribution of citing patents between 1984 and 2013 and cited patents of the citing patents

	Technological fields	# of citing patents	# of cited patents
1	Food and tobacco products	120	765
2	Distillation processes	8	72
3	Inorganic chemicals	246	1,446
4	Agricultural chemicals	28	182
5	Chemical processes	2,196	16,793
6	Photographic chemistry	1,256	7,245
7	Cleaning agents and other compositions	615	4,009
8	Disinfecting and preserving	253	1
9	Synthetic resins and fibres	1,157	8,381
10	Bleaching and dyeing	220	1,457
11	Other organic compounds	862	4,213
12	Pharmaceuticals and biotechnology	1,589	8,211
13	Metallurgical processes	967	6,998
14	Miscellaneous metal products	1,718	17,640
15	Food, drink and tobacco equipment	107	969
16	Chemical and allied equipment	1,569	15,992
17	Metal working equipment	385	3,918
18	Paper making apparatus	78	1,014
19	Building material processing equipment	110	773
20	Assembly and material handling equipment	815	6,396
21	Agricultural equipment	3	75
22	Other construction and excavating equipment	43	300
23	Mining equipment	20	339
24	Electrical lamp manufacturing	280	1,394
25	Textile and clothing machinery	127	811
26	Printing and publishing machinery	81	582
27	Woodworking tools and machinery	4	41
28	Other specialized machinery	961	8,446
29	Other general industrial equipment	1,789	12,799
30	Mechanical calculators and typewriters	108	882
31	Power plants	166	1,187

32	Nuclear reactors	74	641
33	Telecommunications	10,925	70,093
34	Other electrical communication systems	3,604	28,734
35	Special radio systems	634	4,520
36	Image and sound equipment	1,222	8,105
37	Illumination devices	3,998	21,565
38	Electrical devices and systems	10,222	67,769
39	Other general electrical equipment	17,488	108,016
40	Semiconductors	7,392	53,715
41	Office equipment and data processing systems	17,234	128,846
42	Internal combustion engines	414	2,513
43	Motor vehicles	433	3,320
44	Aircraft	19	247
45	Ships and marine propulsion	47	363
46	Railways and railway equipment	0	5
47	Other transport equipment	547	4,301
48	Textile, clothing and leather	233	2,233
49	Rubber and plastic products	292	1,916
50	Non-metallic mineral products	1,162	10,789
51	Coal and petroleum products	81	731
52	Photographic equipment	1,610	8,571
53	Other instruments and controls	11,316	78,021
54	Wood products	170	1,579
55	Explosive compositions and charges	4	39
56	Other manufacturing and non-industrial	666	5,386
	Total	107,846	745,349

In Study 1, Korea’s comparative technological development is a key concept that we will argue has influenced Korean firms’ international knowledge sourcing. Thus, changes in Korea’s technological development compared to the state of world technological development between 1981 and 2010 are presented at intervals of five years in Table 4. In general, Korea's comparative technological development has increased over time. Even though the level of Korea's technological development compared to world technological development was relatively low during the 1980s, Korea has developed remarkable technological capabilities recently in certain technological fields, such as Other general electrical equipment, Semiconductors, Office equipment and data processing, and Photographic equipment systems.

Table 4. The share of Korea's comparative technological development across 56 technological fields between 1981 and 2010 (5-year periods, %)

	56 tech fields of KCTD	1981-85	1986-90	1991-95	1996-2000	2001-05	2006-10	Total
1	Food and tobacco products	0.087	0.103	0.540	0.712	0.885	1.379	0.592
2	Distillation processes	0.000	0.000	0.000	0.528	0.417	0.893	0.233
3	Inorganic chemicals	0.000	0.077	0.113	1.158	1.622	2.514	0.897
4	Agricultural chemicals	0.826	0.000	2.146	3.150	4.124	0.943	2.003
5	Chemical processes	0.065	0.580	2.011	6.524	8.297	18.727	6.472
6	Photographic chemistry	0.000	0.000	0.291	2.975	3.610	6.623	2.544
7	Cleaning agents and other compositions	0.032	0.088	0.342	0.972	2.130	3.971	1.372
8	Disinfecting and preserving	0.000	0.056	0.436	0.425	0.821	1.972	0.782
9	Synthetic resins and fibres	0.025	0.148	0.466	0.858	1.598	2.498	0.918
10	Bleaching and dyeing	0.000	0.104	1.445	2.742	2.333	7.002	2.295
11	Other organic compounds	0.053	0.107	0.424	0.730	1.132	1.340	0.692
12	Pharmaceuticals and biotechnology	0.030	0.036	0.198	0.367	0.542	0.951	0.480
13	Metallurgical processes	0.016	0.108	0.591	1.628	2.113	2.767	1.323
14	Miscellaneous metal products	0.090	0.166	0.380	0.780	1.173	1.872	0.801
15	Food, drink and tobacco equipment	0.066	0.053	0.407	1.248	2.117	2.037	0.938
16	Chemical and allied equipment	0.007	0.029	0.292	1.080	1.066	2.847	0.920
17	Metal working equipment	0.010	0.040	0.160	0.639	0.627	0.989	0.417
18	Paper making apparatus	0.000	0.124	0.156	0.224	0.485	0.513	0.263
19	Building material processing equipment	0.000	0.627	2.841	8.293	12.749	13.918	5.756
20	Assembly and material handling equipment	0.012	0.164	0.790	1.788	1.355	2.430	1.104
21	Agricultural equipment	0.000	0.000	0.000	0.118	0.000	0.000	0.021
22	Other construction and excavating equipment	0.000	0.250	0.688	1.808	1.500	1.931	1.122
23	Mining equipment	0.000	0.000	0.059	0.063	0.089	0.103	0.060
24	Electrical lamp manufacturing	0.000	1.544	8.027	6.577	7.664	12.554	7.684
25	Textile and clothing machinery	0.025	0.049	0.138	0.317	1.249	1.746	0.455
26	Printing and publishing machinery	0.000	0.096	0.105	0.500	0.441	1.459	0.425
27	Woodworking tools and machinery	0.000	0.000	0.000	0.534	0.000	0.223	0.126
28	Other specialized machinery	0.058	0.082	0.267	0.812	1.331	2.340	0.864
29	Other general industrial equipment	0.036	0.116	0.413	1.403	1.760	2.544	1.062
30	Mechanical calculators and typewriters	0.096	0.073	0.920	2.482	1.697	3.111	1.367
31	Power plants	0.000	0.192	0.390	0.718	0.491	0.994	0.530
32	Nuclear reactors	0.000	0.069	0.072	1.157	3.265	6.478	0.871
33	Telecommunications	0.119	0.156	1.122	3.263	3.765	6.081	4.109
34	Other electrical communication systems	0.030	0.298	2.488	4.048	2.627	4.158	3.140
35	Special radio systems	0.000	0.139	0.187	1.095	2.196	3.654	1.913

36	Image and sound equipment	0.032	0.117	1.803	2.258	1.851	1.849	1.615
37	Illumination devices	0.052	0.244	3.212	3.733	6.456	11.510	5.929
38	Electrical devices and systems	0.026	0.333	1.129	4.257	4.711	11.429	4.933
39	Other general electrical equipment	0.059	0.557	4.625	9.453	10.774	17.651	8.983
40	Semiconductors	0.161	0.886	14.337	26.511	44.194	57.918	38.787
41	Office equipment and data processing systems	0.046	0.613	4.762	13.217	12.332	25.403	13.725
42	Internal combustion engines	0.037	0.095	0.306	0.906	1.023	1.300	0.699
43	Motor vehicles	0.000	0.228	0.340	1.122	1.785	1.807	1.172
44	Aircraft	0.000	0.000	0.000	0.240	0.179	0.107	0.104
45	Ships and marine propulsion	0.540	0.297	0.190	0.164	0.201	1.711	0.508
46	Railways and railway equipment	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	Other transport equipment	0.066	0.180	0.659	1.143	1.127	2.437	1.142
48	Textile, clothing and leather	0.340	0.409	0.656	1.092	2.067	2.207	1.264
49	Rubber and plastic products	0.000	0.127	0.303	0.698	1.037	1.808	0.685
50	Non-metallic mineral products	0.035	0.036	0.264	0.631	1.146	2.066	0.752
51	Coal and petroleum products	0.113	0.000	0.033	0.460	0.437	0.919	0.289
52	Photographic equipment	0.000	0.429	5.431	25.050	14.963	31.601	15.645
53	Other instruments and controls	0.034	0.083	0.442	1.906	3.136	5.556	2.499
54	Wood products	0.000	0.282	0.130	0.389	0.726	1.175	0.561
55	Explosive compositions and charges	0.000	0.000	0.000	0.323	0.664	0.000	0.212
56	Other manufacturing and non-industrial	0.068	0.151	0.261	0.442	0.734	1.127	0.494
	Total	0.041	0.156	0.867	2.386	3.109	6.096	2.596

In Study 2, we investigate the relationship between the relative openness of an industry and its knowledge sourcing internationally and locally. First, in order to measure the degree of openness of an industry to foreign countries, we use an industry's export-intensity and inward FDI as proxies. Thus, export-intensity and inward FDI in each industry and each year was collected and calculated. (See more details of the data sources in section 5.3 in Study 2). The average of export-intensity and of inward FDI from 2002 to 2010 are shown in Table 5.

Table 5. Export intensity and inward FDI of industries (average, 2002-2010)

	Industry	Export intensity (%)	Inward FDI (%)
1	Food, drink and tobacco	5.8	0.01
2	Chemicals	51.46	2.64

3	Pharmaceuticals	8.55	0.32
4	Metals	20.53	0.76
5	Mechanical engineering	36.58	1.76
6	Electrical equipment	40.18	2.47
7	Office equipment	27.79	2.98
8	Motor vehicle	51.14	6.19
9	Aircraft and other transport equipment	74.32	0.55
10	Textile	44.09	0.79
11	Paper products, printing and publishing	14.44	0.12
12	Rubber products	36.94	0.00
13	Non-metallic mineral products	8.89	0.19
14	Coal and petroleum products	50.10	1.38
15	Professional and scientific instruments	1.38	0.59
16	Other manufacturing	26.14	0.01

Next, we match the primary technological fields to each industry by using the concordance scheme developed by Qui and Cantwell (2017). It needs to be noted that the technological fields of individual patents are different from the industry of assignees or their corporate group. The firms of all industries are active in multiple fields. Thus, the primary technological fields of each industry are identified and presented in Table 6.

Table 6. The primary technological fields of each industry

	Industry	Primary technological fields
1	Food, drink and tobacco	1,15
2	Chemicals	2,3,4,5,7,8,9,10,11,16,55
3	Pharmaceuticals	12
4	Metals	13,14,17
5	Mechanical engineering	20,21,22,28,29
6	Electrical equipment	24,32,33,34,35,36,37,38,39,40
7	Office equipment	30,41
8	Motor vehicle	42,43,47
9	Aircraft and other transport equipment	31,44,45,46
10	Textile	25,48
11	Paper products, printing and publishing	18,26,27
12	Rubber products	49
13	Non-metallic mineral products	19,50
14	Coal and petroleum products	23,51
15	Professional and scientific instruments	6,52,53
16	Other manufacturing	54,56

Source: R. Qiu and J. Cantwell, 2017 “The international geography of general purpose technologies (GPTs) and internationalization of corporate innovations.”, Industry and innovation, Vol 21, 2017

To investigate the impact of an industry’s export-intensity and inward FDI on its international knowledge sourcing and on the extent of its knowledge sourcing from other Korean industries within the home country, a 3-year lag between the date of an industry's export-intensity and inward FDI and the year of its citing patents is allowed to take account of the delay between the time of the invention and the date of grant of a patent. Therefore, the period for the citing patents by industry is from 2005 to 2013, which is matched to export-intensity and inward FDI data from 2002 to 2010. The distribution of citing patents between 2005 and 2013 by industry is reported in Table 7. In Table 7, the industry classification of citing patent is treated as the primary industry of the corporate group of the assignee, so all the patents of a firm are grouped together in a single industry. A firm's primary industry can be identified based on the firm's economic activities and output or sales. To classify firms by industry, we used the Korean Standard Industrial Classification that is published by Statistics Korea. It is established following the International Standard Industrial Classification of the United Nations. All the Korean firms in Study 2 are classified by this standard. Thus, all the citing patents of firms which have more than 5 citing patents are matched with their firms' primary industry, aggregated into a 16 industry classification. In the case of industry classification for cited patents, firms to cited patents belong are dispersed all over the world, and it is impossible to identify all the cited patents' primary industry by firm because these are simply too many. Thus, we identify the industrial distribution of cited patents by using the primary technological fields of each industry as shown in Table 7.

Table 7. Distribution of the citing patents (2005 – 2013) and their all cited patents by industry

	Industry	Citing patents	Percent (%)	Cited patents	Percent (%)

1	Food, drink and tobacco	41	0.06	514	0.11
2	Chemicals	3,602	5.54	30,563	6.47
3	Pharmaceuticals	489	0.75	3,300	0.70
4	Metals	1,164	1.79	14,565	3.08
5	Mechanical engineering	1,537	2.37	14,185	3.00
6	Electrical equipment	36,242	55.78	243,462	51.55
7	Office equipment	11,209	17.25	90,364	19.13
8	Motor vehicle	791	1.22	5,886	1.25
9	Aircraft and other transport equipment	91	0.14	778	0.16
10	Textile	69	0.11	795	0.17
11	Paper products, printing and publishing	52	0.08	806	0.17
12	Rubber products	119	0.18	958	0.20
13	Non-metallic mineral products	618	0.95	6,242	1.32
14	Coal and petroleum products	40	0.06	499	0.11
15	Professional and scientific instruments	8,637	13.29	56,527	11.97
16	Other manufacturing	271	0.42	2,859	0.61
	Total	64,972	100.00	472,303	100.00

Source: Own database

4. Changes in the comparative technological development of Korea and international knowledge sourcing

4.1. Introduction

Previous studies of international knowledge sourcing focused mainly on the impact of firm level factors or conditions in a host country or location: subsidiary technological capabilities (Almeida, 1996; Frost, 2001; Song et al., 2011), parent technological capabilities (Song and Shin, 2008), mandates of subsidiary and locational characteristics of a host country (Almeida & Phene, 2004; Cantwell & Mudambi, 2005; Phene & Almeida, 2008), knowledge transfer within the MNCs (Almeida et al., 2002; Asakawa, 2001; Phene, Madhok, & Liu, 2005), embeddedness in a host country (Song et al., 2011; Tallman & Phene, 2007) and a host country's technological capabilities (Song & Shin, 2008). Other studies show that on average MNCs still conduct a major portion R&D in their home countries (Belderbos, Leten, & Suzuki, 2013; Blomkvist, Kappen, & Zander, 2011; Di Minin & Bianchi, 2011; Dunning & Lundan, 2008; Patel & Pavitt, 1991). Even in those studies, they also emphasize that home country (parent firm) R&D depends a good deal on international knowledge sourcing through its foreign-located MNC network because they still tend to have a significant R&D presence through their subsidiary networks abroad in foreign countries. Thus, subsidiaries in host countries are used to tap into international knowledge sources for parent firms that then utilize this knowledge back in the home country. The capability of subsidiaries to play this knowledge seeking role is enhanced when they have competence-creating mandates (Cantwell & Mudambi, 2005). Thus, knowledge sourcing through subsidiaries in foreign countries is possible, when MNCs have a significant level of R&D activities abroad. However, in the case of Korea, R&D activities are extremely concentrated in the home country, and so knowledge sourcing from foreign countries through relying upon a network of competence-creating subsidiaries is highly constrained because so little of their R&D activities is conducted.

A home country's technological development is important because technological changes in a country tend to follow a country-specific path or technological trajectory (Vertova, 1999). Although corporate technological diversification has increased due to the rising complexity of knowledge and a steady accumulation of complementary knowledge (Cantwell & Piscitello, 2000), knowledge sourcing as inputs into the development of more advanced technological knowledge is mostly from related technological fields rather than completely different fields. Moreover, a country with weak internationalization of R&D develops the majority of its technological knowledge at home, and direct connectivity to host countries or knowledge accessibility through subsidiaries is relatively low. Thus, in this context the country is greatly constrained by its own resources for domestic technological development.

South Korea is a country that has had a weak internationalization of R&D like Japan, but even more so. It has successfully transformed from being a follower in technological development to becoming front-runner over the last few decades. The successful development in Korea's technological capabilities despite a lack of internationalization of R&D provides an interesting standpoint from which to analyze Korean firm's international knowledge sourcing behavior. In this study, we focus on the conditions for technological dispersion in international knowledge sourcing, and the drivers of the geography of international knowledge sourcing. By studying these issues in the Korean context, we can better understand international knowledge sourcing in an environment in which the traditional route for such sourcing (internal knowledge transfer within the MNC) has been greatly inhibited. Thus, we raise a research question for Study 1.

Research question for study 1*: How does Korea's comparative technological development influence Korean firms' international knowledge sourcing, its degree of technological field dispersion, and knowledge sourcing from foreign countries with traditionally rich technological knowledge resources?*

In this study, the state of comparative technological development of Korea will be considered as a changing environment that sets the context for Korean firms' knowledge sourcing behavior internationally. First, we will study the relationship between Korea's comparative technological development, and its international knowledge sourcing in general. Second, we analyze how the level of comparative technological development in Korea affects the division between inter- vs. intra-field knowledge sourcing from foreign countries. Third, we will investigate how changes in the state of comparative technological development influences the likelihood of firms' sourcing knowledge from foreign countries with traditionally richer technology resources. Lastly, we will examine the impact of the changes in Korea's comparative technological development position in the world on changes in the location of knowledge sources across the foreign countries with traditionally richer technological resources.

Study 1 proceeds as follows. In the next section, we elaborate on the hypotheses development with theoretical arguments. We then describe our data, models and measures. The following section presents the results of the empirical analysis. In the final section, we include our findings and a discussion of the results

4.2. Theoretical development and hypotheses

Korea's level of comparative technological development and international knowledge sourcing

The concept of an "investment development path (or cycle)" (IDP) was introduced by John H. Dunning (1982) as an extension of the OLI paradigm which consists of ownership advantage, location advantage, and internalization advantage. The IDP theory explains the relationship between a country's level of economic development and its international investment patterns. The IDP theory was further developed by Dunning and other scholars (Andreff, 2002, 2003; Dunning, 1986, 1993, 2001; Dunning & Narula, 1996; Duran & Ubeda, 2005; Kalotay, 2006; Kyrkilis & Pantelidis, 2003; Luo et al., 2010; Pantelidis & Kyrkilis, 2005; Stoian, 2013; Tolentino, 1993, 2010; Wei & Alon, 2010).

The main idea of the IDP is that as a country develops, changes in the location advantages of a country and ownership advantages of firms influence the country's inward FDI and outward FDI. This idea can be applied to a country's FDI patterns but also to its knowledge sourcing patterns. At the beginning of early stage technological development, a country is more likely to engage in international knowledge sourcing due to the lack of endogenous knowledge in the home country. A country's technological development is a cumulative process. Over time, as the country develops internal technological knowledge, even more technological knowledge is gradually accumulated or built up in the home country. The country's technological development can generate new location advantages in the home country so that firms in the country can source and exploit more knowledge at home. Therefore, during the early stages of a country's technological development, international knowledge sourcing decreases as the country's own technologies and knowledge resources are developed.

However, this decreasing pattern is liable to be reversed once the country reaches a higher level of technological development. A country with larger technological capabilities tend to engage in more activities in foreign countries because local firms can access more diverse and advanced technological knowledge. (Duran & Ubeda, 2005; Stoian & Filippaios, 2008a). As the country accumulates a higher level of internal technological capabilities, even more diverse and advanced technological knowledge is needed in order to develop its own technological capabilities further. Since every country has a distinctive range of technological knowledge and technological advantages (i.e. it has some focus of specialization), firms in the home country are more likely to source knowledge from foreign countries when they need to obtain a more diverse and advanced array of technological knowledge. Thus, once a country's technological development reaches a higher level, international knowledge sourcing tend to begin to increase again. Accordingly, we formulate the following hypothesis:

Hypothesis 1: A U-shaped relationship is expected between Korea's level of comparative technological development and Korean firms' international *knowledge sourcing.*

Korea's level of comparative technological development and inter- vs. intra-field international knowledge sourcing

Knowledge becomes complex through a recombination of a variety of fields of antecedent knowledge in novel forms of association (Arthur, 2007; Olsson & Frey, 2002; Weitzman, 1998). Previous studies have suggested that building innovation and complex knowledge are key sources of competitive advantage (Celo, Nebus, & Wang, 2015; Fleming & Sorenson, 2001; Frenken, 2006). As a country's technological knowledge is steadily accumulated and further developed, its knowledge tends to become more complex and to contribute to its competitiveness. Recombination of technologically distant knowledge helps to engender more complex and value-creating forms of innovation (Kaplan & Vakili, 2015), and this develops the existing technological knowledge of a country further. Sourcing diverse knowledge internationally is important because knowledge is increasingly dispersed over the world and individual countries have competitive advantages in different technological fields. Thus, a country with more advanced kinds of technological development is more likely to source inter-field knowledge internationally, i.e., to combine knowledge across different fields, which is typically more ambitious.

Moreover, the national level of technological development depends on the technological fields under consideration. For example, Germany has a strong position in chemical areas, while South Korea and Japan have strong technological capabilities in electronics. High development fields in a country such as electronics in Korea, needs more diverse technological knowledge in order to construct more sophisticated kinds of knowledge combination. Thus, high development fields tend to strengthen the positive relationship between Korea's level of technological development and inter-field international knowledge sourcing.

Hypothesis 2a: As Korea moves to comparatively higher levels of technological development, Korean firms are more likely to engage in inter-field international knowledge sourcing.

Hypothesis 2b: The high development fields positively moderate the relationship between Korea's level of comparative technological development and Korean firms' inter-field international knowledge sourcing.

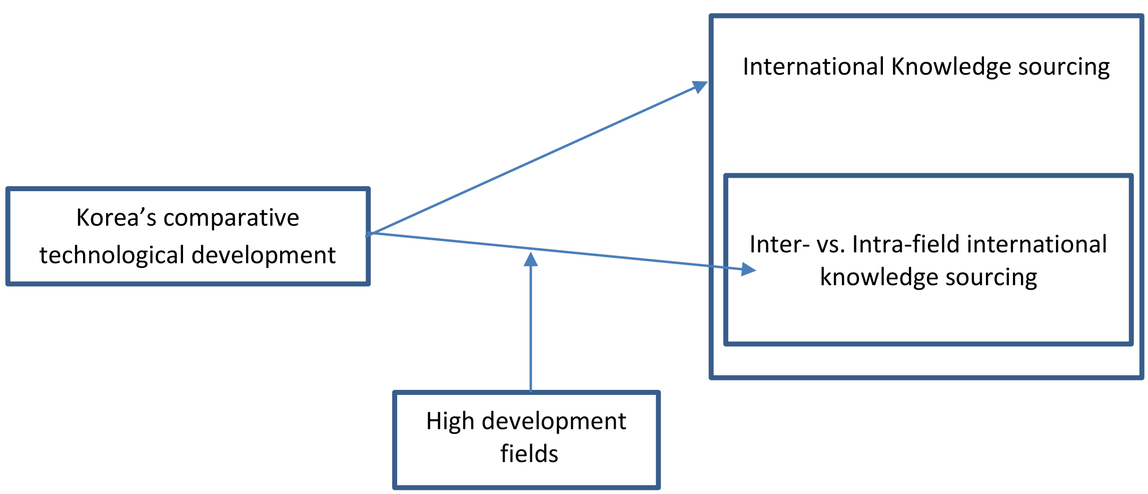

Figure 2. Technological dispersion in international knowledge sourcing (H1, H2a & H2b)

Korea's level of comparative technological development and geography of international knowledge sourcing

The extent of prior technological accumulation that can be further build upon is an important constituent in the capacity of firms to increase the intensity of their innovation (Nelson & Winter, 1982). Accumulating knowledge through learning and building up firm level capabilities are vital elements of any successful catch-up process (Bell & Pavitt, 1993; Lall, 2001). In order to begin to catch-up and accumulate basic knowledge foundations, a certain level of imitation of what has already been achieved in foreign countries is necessary especially in any initial period of basic technological capability building (Kim, 1997). Locations characterized by a wider range of abundant knowledge resources are more likely to become sources to learn from and initiate when first catching up, because they provide the diversity of technological knowledge from which to drew when moving from a low level to a high level of capabilities. Thus, in the early stages of a country's technological development, firms are more likely to source knowledge from foreign countries with traditionally richer technological knowledge resources because they have a greater breadth of knowledge available, and because the wide range of such resources increases the likelihood that at least some of them are accessible. At this early stage, firms' monitoring and searching abilities are relatively low, they have limited information about where the necessary technological knowledge exists. Even with a low level of monitoring and searching abilities, firms can access technological knowledge more readily from countries with traditionally richer technological knowledge resources than they can from other foreign countries, due to the breadth of their abundant knowledge resources. Furthermore, there likely to be quite a high cost involved in establishing knowledge-based relationships across many foreign locations, especially when firms have only limited monitoring and searching capabilities. Thus, firms tend to build relationships only gradually and initially with relatively few foreign places, since it would become very costly to search more widely or globally in the earlier stages of technological development. For these reasons, knowledge sourcing from foreign countries with traditionally richer technological knowledge resources tends to be more dominant at an early stage of a country's technological development.

As a country's own technologies develop further, its relative status in technological development changes. This leads to changes in the objectives of search and consequent shifts in the locations of knowledge sourcing. In the process through which the firms of a country accumulate steadily more technological knowledge, firms from that country begin to become more likely to disperse their search for innovative knowledge across geographic space, and to have a more global knowledge search strategy (Cantwell & Janne, 1999). As a country's level of technological accumulation and development rises, firms from the country tend to diversify the geographic spread of their technological search and to reach out over a wider diversity of locations. Consequently, the trend to focus on knowledge sourcing from a relatively few foreign countries with traditionally richer technological knowledge resources that may aid in catching up tends to shift towards knowledge sourcing from across a wider range of potential knowledge sources. Also, searching and monitoring abilities are improved as more technological knowledge is accumulated. Since firms can begin to identify complementary knowledge sources in other foreign countries in addition to those with the richest knowledge resources, they tend to pursue the geographic diversification of their knowledge sourcing.

These arguments imply the following hypothesis.

Hypothesis 3: An inverted U-shaped relationship is expected between Korea's level of comparative technological development and Korean firms' knowledge sourcing from foreign countries with traditionally richer technological knowledge resources compared to other foreign countries.

In Hypothesis 3, although we expect that as Korea's technological capabilities develop further, knowledge sourcing from foreign countries with traditionally richer technological knowledge resources turns down past some point, these countries remain major sources. They account for around 79% of total international knowledge sourcing over the period as a whole. (see Appendix A3). Therefore, it is relevant to examine changes in the geographic composition of knowledge sourcing among these foreign countries with traditionally richer technological knowledge resources.

Geographical proximity is important to social connectivity, and hence knowledge spillovers are geographically bounded (Jaffe, 1986; Jaffe et al., 1993) and many channels of communications between organizations are localized (Garcia et al., 2013). In addition to these, geographical proximity helps firms to formally and informally collaborate when developing technological knowledge.

Despite the importance of geographical proximity, several studies have emphasized that knowledge flows may occur globally as well as locally. (Andersson & Karlsson, 2007; Lorentzen, 2008; Geenhuizen, 2008). Many firms with innovation-driven agendas source knowledge internationally as well as from geographically proximate locations (Davenport, 2005). The Uppsala internationalization process model suggests that firms gradually expand their business from psychic and geographically proximate countries to steadily more distant countries (Johanson & Vahlne, 1977; Johanson & Vahlne, 1990). Once more technological knowledge has been accumulated in a country, its monitoring and searching capabilities for technological knowledge from distant foreign countries increases. Thus, we expect that the pattern of Korea's knowledge sourcing tends to gradually shift from proximate countries to distant countries among those foreign countries that have traditionally rich technological knowledge resources. Accordingly, we hypothesize as follows:

> *Hypothesis 4: As Korea moves to more advanced stages of technological development, the share of knowledge sourced from among the foreign countries with traditionally rich technological knowledge resources is likely to gradually shift from a proximate location such as Japan towards more geographically distant locations such as Germany, the UK, and France.*

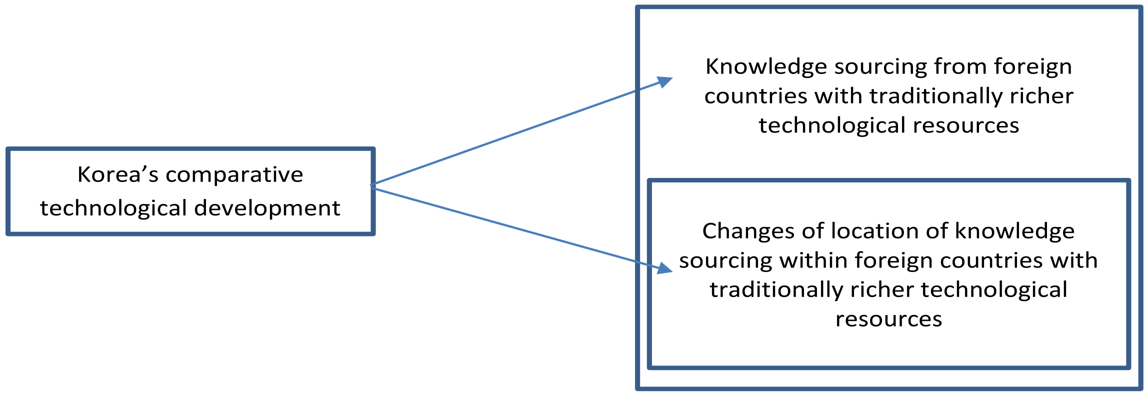

Figure 3. Geography of international knowledge sourcing (H3 & H4)

4.3. Methods

4.3.1. Data

In this study, we analyze how Korea's level of comparative technological development has influenced the technological dispersion in its international knowledge sourcing and the geography of that international knowledge sourcing. Our empirical evidence consists of all the USPTO patents granted for inventions in South Korea throughout the period 1980 – 2013. Since we intend to compare Korea's technological development with technological development in the world as a whole, a total count was made of all USPTO patents granted during the same period too. From these patent records, we use the patent grant year, location of the first inventor, technological classifications of each patent, and citations to earlier patents made by Korean-invented patents (i.e. their knowledge sources).

4.3.2. Variables and measures

4.3.2.1. Dependent variables

International knowledge sourcing. The degree of international knowledge sourcing represents how much firms source knowledge from the foreign countries. The USPTO patent data provide the location information of inventors for each patent. We use the first inventor's location information to distinguish where a patent is invented because the first inventor is a generally the leader of a research team. Considering a pair of citing and cited patents, if a cited patent was invented in a foreign country, then we construct a dummy variable for international knowledge sourcing that takes a value of 1. If a cited patent was invented in South Korea, then we code this variable as equal to 0. Allowing for a 3-year lag between the year of the citing patent in this variable which is our DV and the year of the IV, this indicates the likelihood of international knowledge sourcing yearly from citing patents granted between 1984 and 2013.

Inter-field knowledge sourcing. To measure the presence of inter-field knowledge sourcing, by using a classification into 56 technological fields, when a cited patent is in a different technological field than is a citing patent, we construct a dummy variable that takes a value of 1. If a cited patent belongs to the same technological field as citing patent, we code it as equal to 0. Allowing for a 3-year lag between the year of the citing patent in the DV and the year of the IV, this indicates the likelihood of inter-field knowledge sourcing yearly from citing patents granted between 1984 and 2013.

Share of knowledge sourcing from foreign countries with traditionally richer technological knowledge resources. To distinguish foreign countries with traditionally richer technological knowledge resources from other foreign countries, we use the total number of patents granted in the USPTO patent data base by country of origin. Based on the total number of US patents granted by 2015, five countries, i.e. the US, Japan, Germany, the UK, and France have accumulated a greater number of patents than South Korea (see Table 8). Among these five countries, we exclude the US. The propensity to patent inventions originating in the US is higher historically relative to foreign countries in the USPTO since this constitutes domestic rather than foreign patenting. Given the internationalization of the patent system, part of an observed trend away from the US is attributable to a rise in foreign vs. domestic patenting. For this reason, I include only the other top 4 foreign countries; namely, Japan, Germany, the UK, and France as foreign countries with traditionally richer technological knowledge resources. In this context we consider only cited patents that were invented outside Korea, i.e. we exclude Korean-invented patents as well as US-origin patents.

Table 8. Number of patents granted as distributed by year of patent grant between 1963 and 2015 (Breakout by U.S. and foreign country of origin)[4]

Origin	Pre 2002	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	**All Years**
U.S. And Foreign Origin	3247448	167331	169023	164290	143806	173772	157282	157772	167349	219614	224505	253155	277835	300677	298407	**6122266**
-- Subtotal -- U.S. Origin	1957623	86971	87893	84270	74637	89823	79526	77502	82382	107791	108622	121026	133593	144621	140969	**3377249**
-- Subtotal – Foreign Origin	1289825	80360	81130	80020	69169	83949	77756	80270	84967	111823	115883	132129	144242	156056	157438	**2745017**
JAPAN	485962	34858	35515	35346	30340	36807	33354	33682	35501	44813	46139	50677	51919	53848	52409	**1061170**
GERMANY	242593	11280	11444	10779	9011	10005	9051	8914	9000	12363	11919	13835	15498	16550	16549	**408791**
UNITED KINGDOM	105600	3829	3618	3441	3141	3579	3291	3085	3173	4298	4292	5211	5806	6488	6417	**165269**
FRANCE	93260	4035	3868	3380	2866	3431	3130	3163	3140	4450	4532	5386	6083	6691	6565	**153980**
KOREA, SOUTH	21706	3786	3944	4428	4351	5908	6295	7548	8762	11671	12262	13233	14548	16469	17924	**152835**

When a cited patent was invented in one of the top 4 foreign countries (Japan, Germany, UK, or France) with traditionally richer technological resources, we construct a

[4] https://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_utl.htm, A Patent Technology Monitoring Team Report, USPTO 2015

dummy variable that takes a value of 1. If a cited patent was invented in other foreign countries, we code it as equal to 0. Considering a 3-year lag between the year of the citing patent in the DV and the year of the IV, this indicates the likelihood of knowledge sourcing from technologically richer foreign countries yearly from patents granted between 1984 and 2013.

Share of knowledge sourcing from more distant locations (Germany, the UK, or France) vs. the most proximate location (Japan). Among the top 4 foreign countries with traditionally richer technological resources, Japan is located in East Asia and is near to South Korea, while Germany, the UK and France are located in Western Europe which is a long way from South Korea. Therefore, when a cited patent was invented in distant location; Germany, the UK, and France, we construct a dummy variable that takes a value of 1. If a cited patent was invented in the proximate foreign location; Japan, we code it as equal to 0. Considering a 3-year lag from the IV, we have the likelihood of the knowledge sourcing from more distant places yearly from patents granted between 1984 and 2013.

4.3.2.2. Independent variable

Korea's level of comparative technological development. To analyze the influence of Korea's level of comparative technological development on each of the dependent variables discussed above, we consider Korea's technological development both in each technological field and in each year, compared with technological development in the world as a whole. We specify a 3-year lag between the year of the IV and the year of the citing patent in the DV for two reasons. One is that after a patent is invented, it takes time to be granted in the USPTO, and on average this takes three years. Therefore, a 3-year lag allows for the effect of the interval between the time of the invention and the date of grant of a patent. The other is that we can offset to some extent the possibility of endogeneity by using a lag. In other words, the focal citing patents obviously themselves influence the technological position of Korea because they are in the equivalent fields. But by using a lag, we offset this contingency. Thus, we operationalize Korea's level of comparative technological development as the ratio of the number of patents developed in Korea in each technological field and in each year from 1981 to 2010 relative to the total number of patents developed in world in the same technological field and in the same year.

$$\text{Korea's level of comparative technological development} = \frac{K_{ij}}{W_{ij}} \times 100$$

Where:
K_{ij} is the number of patents developed in Korea in technological field *i* (*i* = 1, . . . , 56) in a given year *j* (*j* = 1, . . . , 30).
W_{ij} is the number of patents developed in the world in technological field *i* (*i* = 1, . . . , 56) in a given year *j* (*j* = 1, . . . , 30).

4.3.2.3. Control variable

Samsung & LG dummies. In our citing patent samples, around half of the citing patents come from two large Korean firms; Samsung Electronics and LG Electronics. There might be some firm-specific effects associated with these two firms. Thus, we include two dummy variables for Samsung Electronics and LG Electronics for a more accurate analysis of all Hypotheses in Study 1.

4.3.3. Samples and model

Our four dependent variables are all binary count variables. A Poisson distribution model is suggested in this case if there is no heterogeneity in the sample. However, there may be unobserved heterogeneity in our sample which results in an underestimation of the standard errors and an inflation of the significance levels. This over-dispersion issue can be corrected by applying negative binomial regression models (Hausman et al, 1984; Kogut & Chang, 1991). Moreover, the negative binomial regression is more conservative than the Poisson regression model because negative binomial regression models report the exactly same results as those of Poisson regression even in the case of no presence of over-dispersion. Therefore, we employ a negative binomial regression to investigate the effects of the Korea's level of comparative technological development on the technological dispersion and on the geography of international knowledge sourcing.

4.4. Results

We present descriptive statistics for all the variables used in this study in Table 9. All four dependent variables are observed over a 30 years period. (See more details for the observations of each dependent variable in Appendix A1, Appendix A2, Appendix A3, and Appendix A4.)

Table 9. Summary of descriptive statistics

	Variable	Mean	Std. Dev.	Min	Max
1	International knowledge sourcing (DV1)	0.8789	0.3274	0	1

2	Inter-field knowledge sourcing (DV2)	0.3689	0.4825	0	1
3	Share of knowledge sourcing from foreign countries with traditionally richer technological knowledge resources (DV3)	0.7909	0.4067	0	1
4	Share of knowledge sourcing from proximate location vs. distant location (DV4)	0.1482	0.3553	0	1
5	Korea' level of comparative technological development (KCTD)	12.1283	13.8542	0	62.4366
6	High development fields (HDF)	0.4148	0.4927	0	1

The results of the negative binomial regression are reported in Table 10. Model 1 analyzes our first hypothesis that there is a U-shaped relationship between Korea's level of comparative technological development and Korean firms' international knowledge sourcing. Model 2 tests how Korea' level of comparative technological development influence Korean firms' inter- vs. intra-field knowledge sourcing internationally. A high development field variable is included in Model 3 as a moderator for the relationship between variables in Model 2. This identifies the fields in which Korea's technological development has been most outstanding. In Model 4, we analyze the relationship between Korea's level of comparative technological development and knowledge sourcing from foreign countries with traditionally richer technological resources. Finally, Model 5 tests how the geography of international knowledge sourcing has changed among the foreign countries with traditionally richer technological resources, depending upon the level of Korea's attained by comparative technological development.

In Model 1, the coefficient on the linear term of Korea's level of comparative technological development is negative and significant (Model 1: $\beta = -0.0050$, $p < 0.01$). This means, as Korea's technology develops, international knowledge sourcing decreases during the initial period. However, the coefficient on the quadratic term of Korea's level of comparative technological development is positive and significant (Model 1: $\beta = 0.0001$, $p < 0.01$), indicating a U-shaped relationship. Thus, this result supports Hypothesis 1. In Model 2, the relationship between Korea's level of comparative technological development and inter-field international knowledge sourcing is positive and significant (Model 2: $\beta = 0.0039$, $p < 0.01$), providing support to Hypothesis 2a. Model 3 tests Hypothesis 2b, which predicts a positive interaction between the Korea's level of comparative technological development and the fields of high development for Korea. The interaction is negative and significant (Model 3: $\beta = -0.0075$, $p < 0.01$), not supporting Hypothesis 2b. Model 4 examines Hypothesis 3, which proposes an inverted U-shaped relationship between Korea's level of comparative technological development and knowledge sourcing from foreign countries with traditionally richer technological resources. The coefficient on the linear term of Korea's level of comparative technological development is significant and positive (Model 4: $\beta = 0.0019$, $p < 0.01$) while the quadratic term is significant and negative (Model 4: $\beta = -0.0001$, $p < 0.01$), thereby indicating an inverted U-shaped relationship. Thus, Hypothesis 3 is supported. The results for changes in the geography of international knowledge sourcing from a proximate location (Japan) to more distant locations (Germany, the UK, and France) within the top 4 foreign countries with rich knowledge resources are presented in Model 5. However, the hypothesis is not supported. It is statistically significant but the result shows more knowledge sourcing from Japan than from Germany, the UK or France as

Korea's technology has developed further, which is the reverse of our expectation in Hypothesis 4 (Model 5: β = -0.0219, p < 0.01).

Table 10. Negative binomial regression models

Dependent variables	Model				
	1 DV1	2 DV2	3 DV2	4 DV3	5 DV4
Samsung & LG dummies	Included	Included	Included	Included	Included
KCTD	-0.0050 (0.0002)***	0.0039 (0.0001)***	0.0160 (0.0006)***	0.0019 (0.0004)***	-0.0219 (0.0005)***
KCTD^2	0.0001 (0.0000)***			-0.0001 (0.0000)***	
HDF			-0.1940 (0.0070)***		
KCTD x HDF			-0.0075 (0.0007)***		
Observations	745,349	654,347	654,347	349,957	269,652
Log likelihood	548.25	1424.19	3406.19	134.97	4035.48

*p < 0.10, **p < 0.05; *** p < 0.01.

The results of the tests of statistical significance are shown in Table 10. Although these tests of statistical significance demonstrate how Korea's level of comparative technological development affects our dependent variables, they do not show the economic importance (the magnitude of impact) of these effects. For this purpose, it is necessary to analyze the effect sizes of each of the results. Thus, we provide the estimates of linear effects for each pair of independent variable and dependent variable in each Hypothesis. We find that as Korea's comparative technological development changes, 1) around an 8% change (between 81% and 89%) in international knowledge sourcing (Figure 4), 2) around a 9% change (between 35% and 44%) in inter-field international knowledge sourcing (Figure 5), 3) around a 6% change (between 74% and 80%) in knowledge sourcing from the top 4 foreign countries with richer knowledge resources (Figure 6), and 4) around a 15% change (between 3% and 18%) in knowledge sourcing from more distant locations within the top 4 foreign countries with richer knowledge resources (Figure 7).

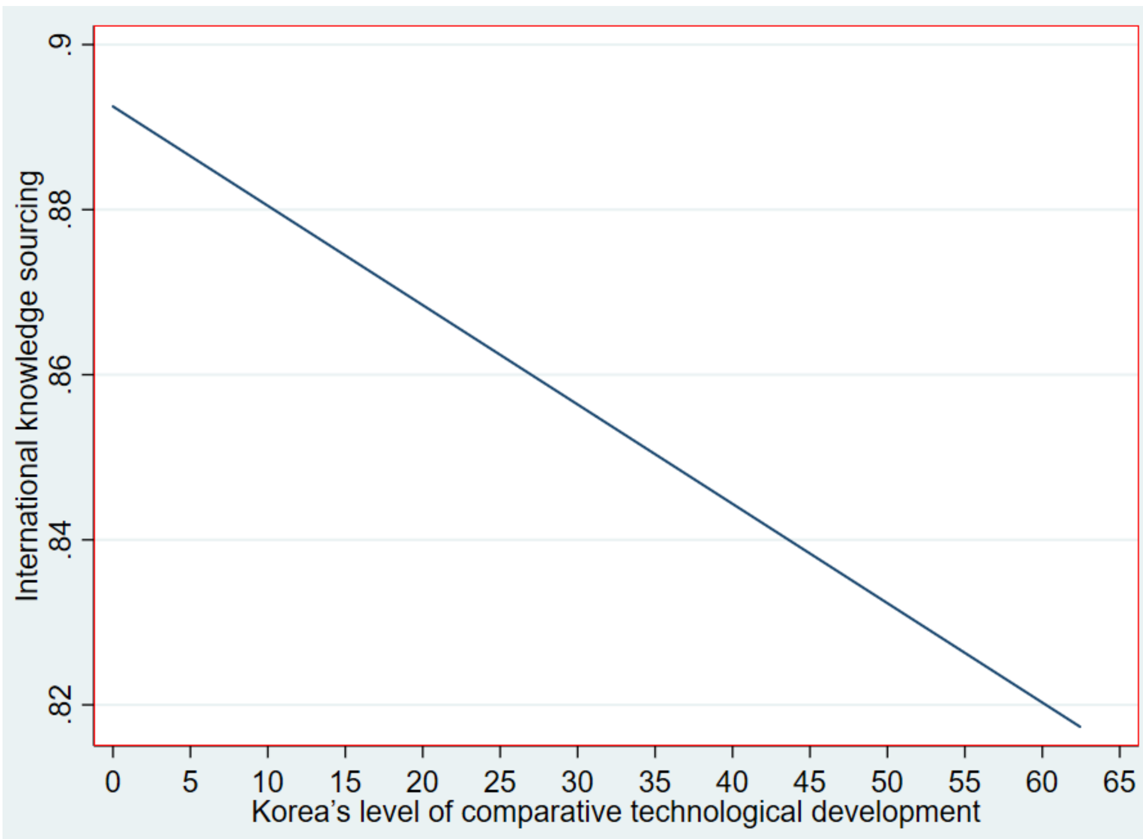

Figure 4. Effect size of Korea’s level of comparative technological development on international knowledge sourcing

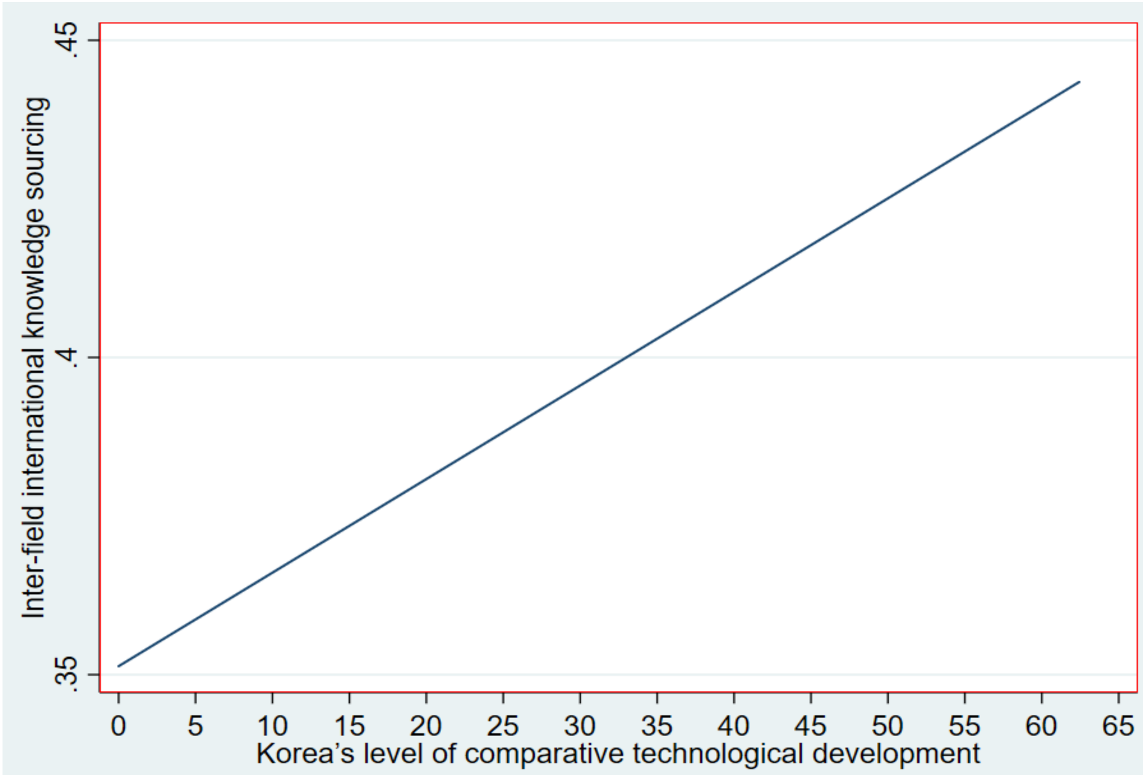

Figure 5. Effect size of Korea's level of comparative technological development on Inter-field international knowledge sourcing

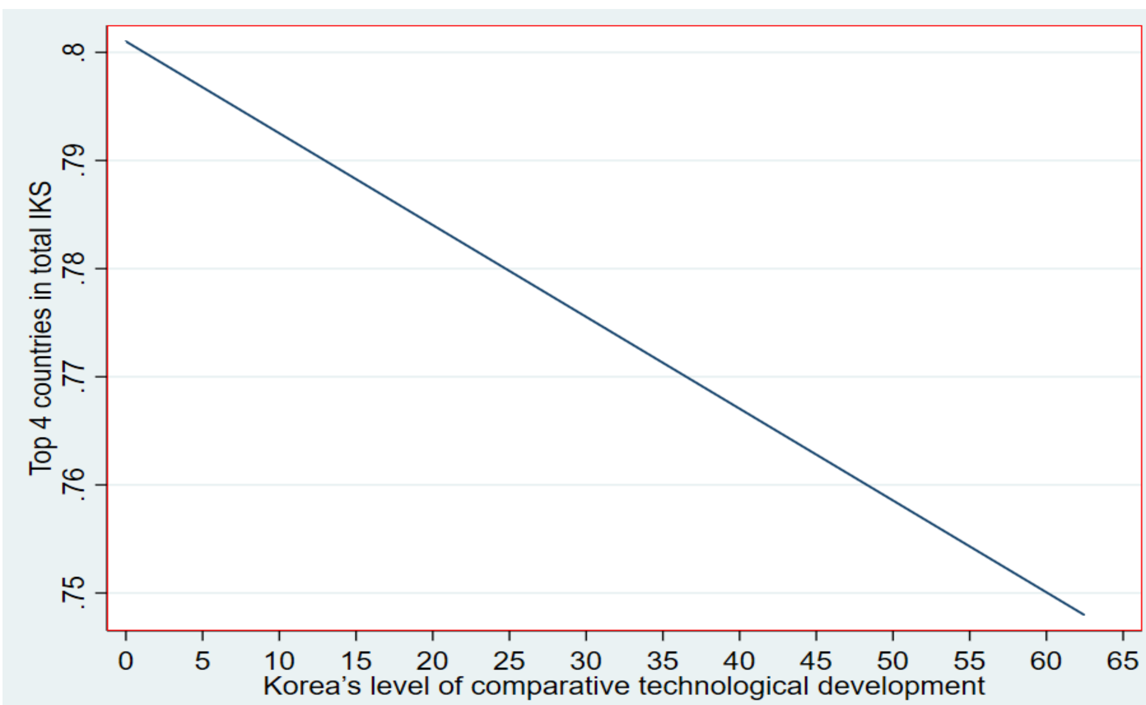

Figure 6. Effect size of Korea's level of comparative technological development on knowledge sourcing from top 4 foreign countries with richer knowledge resources in total international knowledge sourcing

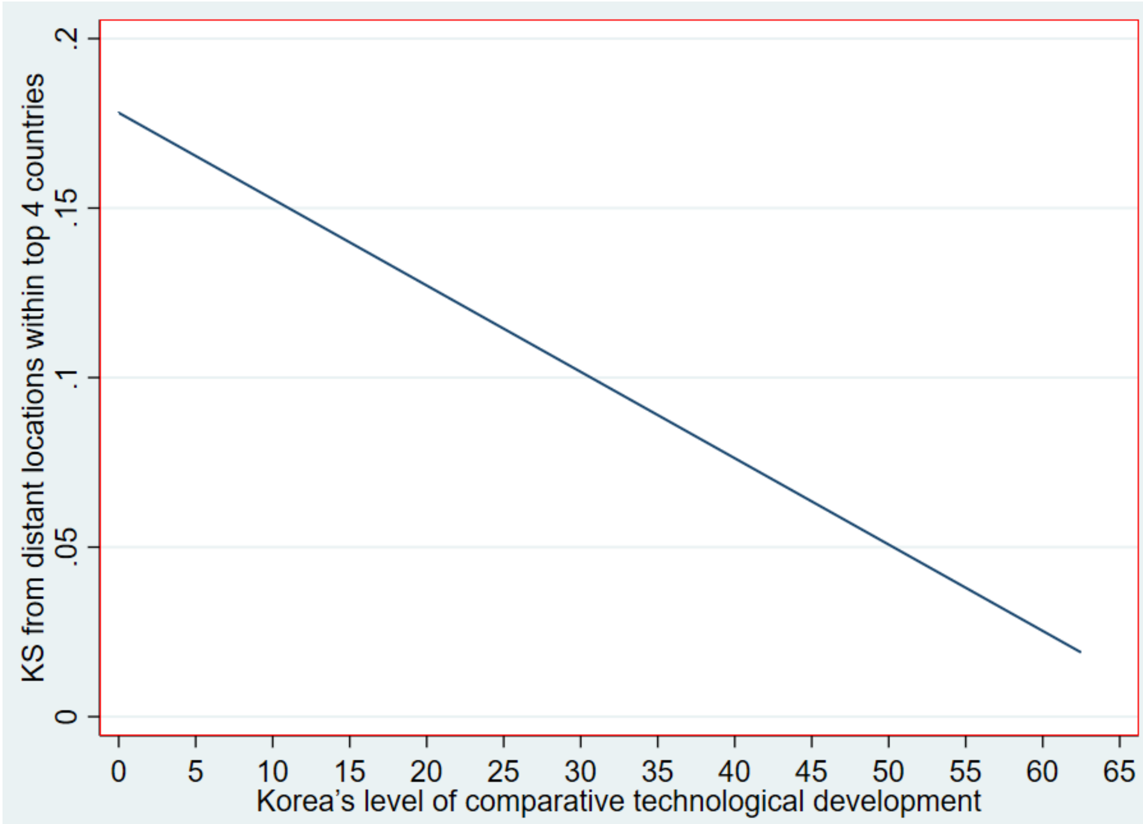

Figure 7. Effect size of Korea's level of comparative technological development on knowledge sourcing from distant locations within top 4 foreign countries with richer knowledge resources

4.5. Discussion

This study explores how a country's level of comparative technological development influences its firms' international knowledge sourcing, a critical idea largely overlooked in international knowledge sourcing literature, especially in conditions in which the internationalization of R&D has been week. To understand the effects of a country's level of comparative technological development, we investigated its influence on international knowledge sourcing in general, on the extent of technological dispersion in international knowledge sourcing, and on the geography of international knowledge sourcing by firms from the country.

In Hypothesis 1, we demonstrate the existence of a U-shaped relationship between Korea's level of comparative technological development and international knowledge sourcing. At an early stage of development, Korean firms tend to increase knowledge sourcing locally as knowledge stock in Korea is accumulated. However, once technological development reaches a certain level, firms tend to increase their international knowledge sourcing again because they now need a broader spread of technological knowledge from sources that are more geographically dispersed from around the world in order to develop more advanced and complex technology. The estimated turning point in this U-shaped relationship is within the observed range of Korea's level of comparative technological development (see Figure 4). We have calculated the percentages of international knowledge sourcing over time in order to estimate the effect of Korea's level of technological development. When Korea's level of technological development reaches around 35% of world technological development, Korean firms' international knowledge sourcing begins to increase again. Among the 56 technology fields, only the field of semiconductors attains the turning point, and other fields have not yet reached the turning point (see Table 4 in the section 3.3.). Thus, the dominant effect is still one of a decrease in international knowledge sourcing in the Korean case.

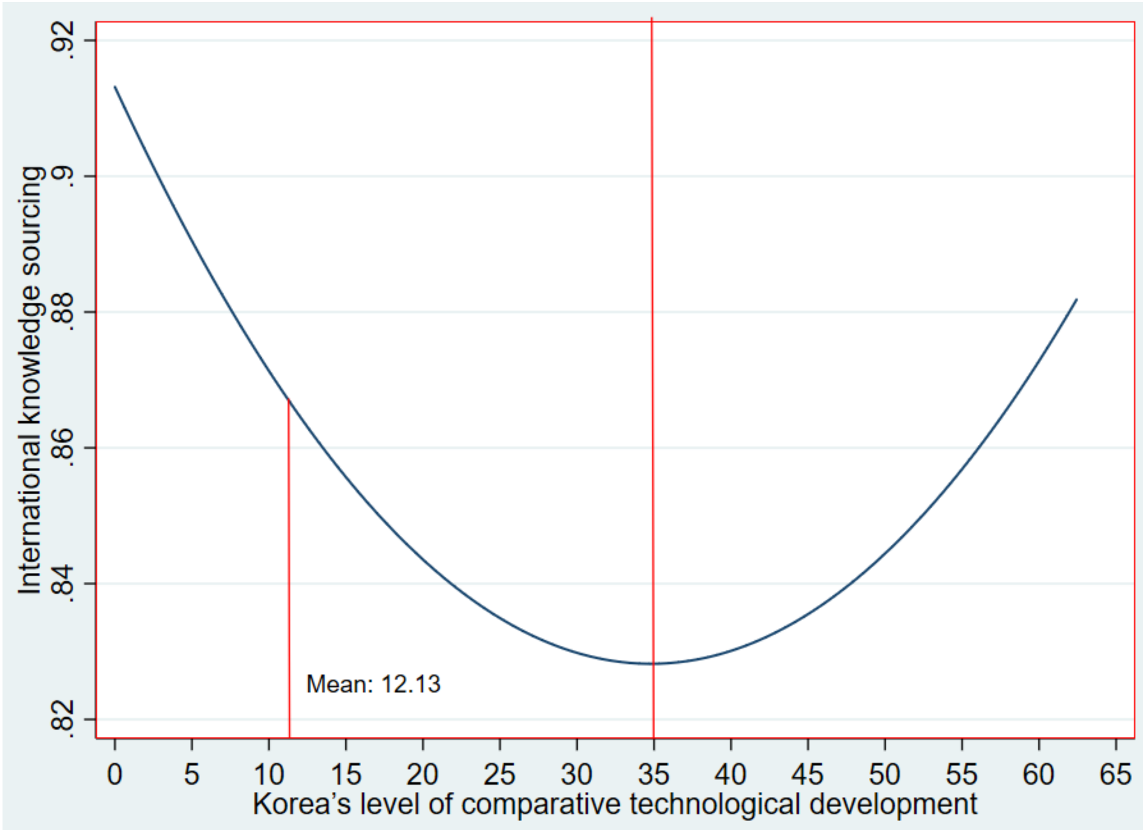

Figure 8. Percentage of international knowledge sourcing depending on Korea's level of comparative technological development

In Hypothesis 3, our finding there is an inverted U-shaped relationship between Korea's level of comparative technological development and the likelihood of sourcing knowledge from foreign countries with traditionally richer knowledge resources suggests that there are differences between international knowledge sourcing in general and the geographic composition of international knowledge sourcing. The estimated turning point of the inverted U-shape appears when Korea's technological development is around 18% of world technological development (see Figure 5). In the case of international knowledge sourcing in general (Hypothesis 1), an upward turn occurs at very high level of domestic development. Korean firms start exploring more abroad only, when they reach a really high level of development (a 35% share of world patenting). However, the inflexion point when examining the geography of international knowledge sourcing (Hypothesis 3) is different. This has more to do with an earlier need for some geographic diversification. This happens earlier at around on 18% share of world patenting). What these findings show is that the point at which firms start geographically diversifying in international sourcing occurs earlier, while the shift from domestic to international knowledge sourcing comes only in a later period.

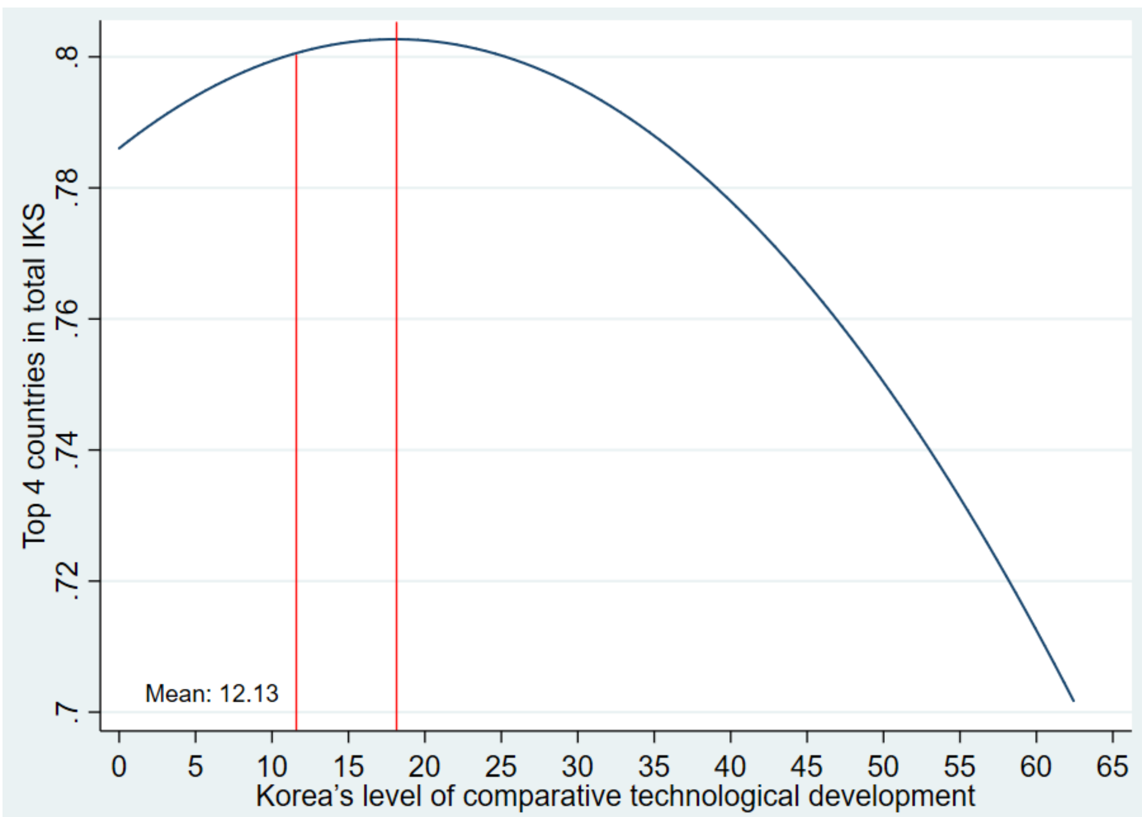

Figure 9. Percentage of knowledge sourcing from top 4 foreign countries with richer knowledge resources in total international knowledge sourcing depending on Korea’s level of comparative technological development

The result of the negative binomial regression analysis for Hypothesis 2a indicates that Korea’s comparative technological development influences the increase in Korean firms’ inter-field international knowledge sourcing. This finding is consistent with Celo, Nebus, and Wang's (2015) argument that firms are more likely to source technologically distant knowledge when they develop more complex or sophisticated knowledge, which may be a key source of competitive advantage as firms progress to higher levels of technological development.

The result of Hypothesis 2b shows, contrary to our expectations, that high development fields (HDFs) are more likely to engage in intra-field international knowledge sourcing, and hence weaken the overall relationship between Korea's level of comparative technological development and Korean firms' inter-field international knowledge sourcing. These unanticipated findings may be explained by the emergence of bilateral knowledge connections between Korea and the rest of the world in HDFs, in which Korea has become a strong global player. Intra-field knowledge sourcing in HDFs is high because they generate a lot of capabilities in their domains. Thus, it is possible that there may be increasing international knowledge exchanges between Korea and the rest of the world in HDFs. In HDFs, Korea is sourcing from other countries, especially from co-specialized locations, and also, we might expect that the co-specialized locations are sourcing more from Korea as Korea has become excellent in these fields. Thus, the share of intra-field citations would rise within HDFs, if they have begun to develop reciprocal international relationships and co-specialization of activity across different key locations. In other words, Korean research would have become more integrated with worldwide research within HDFs.

For Hypothesis 4, we find the reverse of our original expectation, that as Korea's technological position become stronger, the propensity to source knowledge from a proximate location actually become more dominant. A plausible explanation for this is the close economic relationship between Korea and Japan historically. Moreover, and relatedly, Korea's technological specialization has been coming close to Japan's technological specialization. Japan and Korea are becoming increasingly co-specialized, and so Korea has become more reliant on Japan. Japan, a proximate location, is traditionally strong in electronic technologies whereas more distant countries, Germany, the UK and France in Europe, are relatively weak in these fields. Korea has developed strong technological position in the areas of electronic technologies. Thus, Korean firms are more likely to source electronic technologies from Japan which is also strong in these electronic fields. This can be confirmed from the descriptive evidence of Table 4 in the section 3.3. Among the 56 technology fields, the top 5 fields in which Korea has its strongest technological position are Semiconductors (40), Photographic equipment (52), Office equipment & data processing systems (41), Other general electrical equipment (39) and Electrical lamp manufacturing (24). These are all related to the electronic technologies in which both Korea and Japan are strong. Our finding is also consistent with the latest version of Uppsala internationalization process model (Johanson & Vahlne, 2009). This new version focuses on the importance of relevant networks for internationalization, which helps to explain Korea's knowledge sourcing from Japan due to the closer network relationship that exist between Korea and Japan in the electronic fields.

Moreover, there might be three potential drawbacks of the framework I used to construct Hypothesis 4. First, the Uppsala internationalization process model that I referenced does not contain the notion of the potential co-specialization of locations. In the Uppsala model, there are only notions of geographic or cultural distance, but the model does not consider the possibility of the co-specialization of locations in technological knowledge. Although geographic or cultural separation are more central for marketing knowledge, in our study the co-specialization of locations for technological knowledge has greater relevance for the geography of international knowledge sourcing. By using the Uppsala model, my theoretical reasoning has been mainly focused on geographic distance, but neglects the role of the increasing co-specialization in technological knowledge between Korea and Japan as Korea has become a world leader in electronic expertise.

The second limitation is the consideration of novelty in technological discovery. With technological knowledge, novelty is more likely to be valuable. Novelty is not geographically limited, and it may be a more important element than geographical proximity or distance when searching locations for new sources of technological knowledge. When considering the novelty of technology knowledge resources, the arguments of the Uppsala model are not relevant here. Given the co-specialization in electronic fields of Korea and Japan, Korean firms may find more novel knowledge resources in Japan than are available from Germany, the UK, or France.

The last limitation is that we did not consider rapid internationalization. In a fast-changing business environment, some firms with high technological knowledge resources quickly internationalize once they are established (Chang & Lee, 2011; Shrader, Oviatt, & McDougall, 2000). The explanatory power of the traditional Uppsala model has become weaker than it once was because of increasingly rapid internationalization processes in recent years. Since my research is about the internationalization of knowledge search, it is more applicable to the possibility of a rapid internationalization process than is the Uppsala model, which has been more focused upon gradual internationalization processes. If the internationalization of the firm is becoming more rapid, we would expect an even more rapid internationalization of knowledge search. This may potentially weaken our theoretical arguments, which have been developed without considering a rapid internationalization of knowledge search.

5. The Relative openness of an industry and firms' knowledge sourcing behavior

5.1. Introduction

The process of industrialization in Korea relied on international business connections, and most of those took forms other than MNC internal networks. While this differed from the experience of European countries, it shows some similar traits to the industrialization process of Japan. Ozawa (2009) explains the economic development of the emerging economies' success across East Asia through his "flying geese theory". He argues that less developed countries imitate and learn from more advanced economies in order to catch up. Since Japan was the most advanced economy in Asia and it is located close to South Korea as well as, owing to the ties historically and geographically, it was easy to adjust Korea's economic system to Japan's in a short space of time. When compared to other developed economies, Japan shares much in common with Korea. Korean firms have naturally imitated and applied the Japanese system in management and technology development, and then subsequently in creating their own innovations through learning and adaptation. Over time, Korea has developed its strongest positions in the same industries as did Japan in the past. An interesting point here is, in the industrialization process of Japan, Japan had some highly competitive industries which were increasingly internationally connected, but at the same time some other inefficient and protected industries which were more domestic-market-oriented. Just as in the Japanese case, South Korea has also had a dualistic structure among its industries.

By the 1960s, South Korea invested and developed light industries, such as textiles, food, agriculture, and general merchandise, since light industries require a relatively low level of capital equipment. South Korea did not have much capital immediately after the Korean War, and so it naturally focused on light industries to promote general economic growth. It is because light industries are not technology-intensive, but labor-intensive, and Korean wages at that time were very low, similar to some other developing countries these days. As time went by, Korean firms became more competitive and earned foreign currency through exporting light industry goods. From the end of the 1960s and the beginning of the 1970s, heavy industries that needed higher levels of technology such as steel, machinery, electronics, shipbuilding, semiconductor and automobile industry have been more intensively developed. During the 1980s and 1990s, heavy industries had received more investments and further developed. Now, the heavy industries have become the mainstay for South Korea's economy, and they account for the majority of exports. This has been grounded upon their technological achievements in semiconductors, steel, shipbuilding, petrochemicals, and automobile parts. Conversely, the light industries have become less important and more domestic-market-focused. Thus, a low level of technological capabilities is generally observed in light industries.

Moreover, the dualistic structure of Korean industry suggests that there have been two different types of international knowledge connectedness. In the relatively advanced (outer-focused) industries, international connections are strongly developed. In the relatively backward (inner-dependent) industries, international connections are very much weaker. Therefore, this is an appropriate setting in which to consider international knowledge sourcing because we can investigate more directly the effects on knowledge sourcing of differences in the degree of openness and the international connectedness of industries. The Korean form of industrialization has relied upon a certain kind of openness and connectedness to foreign countries, and it has also been associated with capability creation of Korean firms in each industry. Certain industries are better placed to achieve local capability development than others because of the dualistic divide. The dualistic structure of industries as reflected in their different levels of openness and connectedness to foreign countries have made important differences in the capacity to acquire knowledge from abroad, and thereby to develop capabilities.

Thus, we focus here on the effects of the dualistic structure of Korean industries, distinguishing between outer-focused industries and inner-dependent industries, on the knowledge sourcing of Korean firms internationally and domestically. The most distinctive feature of outer-focused industries as compared to inner-dependent industries is their degree of openness and connectedness to foreign countries. A firm's behavior in knowledge sourcing internationally and domestically is likely to be influenced by the relative openness of its industry. Thus, our central research question here is:

Research question: *What are the effects of the relative openness of an industry on Korean firms' international knowledge sourcing and on their knowledge sourcing between industries in the home country?*

In this study, we examine how the relative openness of an industry affects Korean firms' knowledge-sourcing behaviors. We consider two distinctive features of the relative openness of an industry; its export intensity and the extent of penetration by inward FDI. Under the impact of these two factors, we investigate Korean firms' international knowledge sourcing and its relative reliance upon intra- vs. inter-industry knowledge sourcing within the home country.

The remainder of Study 2 is organized as follows. In the next section, we develop our hypotheses with theoretical arguments. In the following section, details of the sample, the data, and measures used to test those hypotheses are described. After presenting the statistical results, we provide our findings in a discussion section.

5.2. Theoretical development and hypotheses

Traditionally, firms have engaged in knowledge sourcing to access new knowledge and to further develop their exiting knowledge. So, under what conditions, have Korean firms behaved differently in terms of knowledge sourcing? In this study, we focus on effect of the relative openness of an industry on Korean firms' knowledge sourcing from abroad and on relationships of knowledge sourcing between Korean industries. Two distinctive features of the relative openness of an industry, the degree of export intensity and the degree of inward foreign direct investment (FDI), are considered to investigate firms' knowledge-sourcing behavior.

Export and international knowledge sourcing

Souring technological knowledge from abroad is one of the forms of learning for developing new technology. One of research streams in the international trade argues "learning-by-exporting" which exporting can be associated with innovation and productivity (Salomon 2006; Andersson & Loof, 2009; Cassiman, et al., 2010; Cassiman & Golovko, 2011). Exporting firms and industries can learn from foreign contacts by accessing and adopting new and diverse technological knowledge that is not obtainable in the home country (Salomon & Shaver, 2005). By exporting, firms become more familiar with the foreign countries where they sell their products. Export-oriented industries analyze the products of their competitors and foreign markets. In this process, export-oriented industries naturally recognize and become more familiar with technological knowledge beyond the environment of the home country. The more industries engage in exports, the more exposure foreign knowledge resources that firms gain to. Since export-oriented industries recognize and become aware of more diverse sources of foreign technological knowledge, they are more likely to source technological knowledge from abroad.

On the other hand, there is the possibility that firms enter into export markets because they are more productive (Greenaway & Kneller, 2007; Wagner, 2007). When firms have more capabilities, they expand their business in foreign countries (Hymer, 1976). Firms with higher technological capabilities want to expand their markets to foreign countries and one of the most prevalent forms of international expansion is exporting. Export-oriented firms have more technical efficiency than import-substitution-oriented firms because they face higher level of competition in world market (Chen & Tang, 1987). Since export-oriented industries have higher technological capabilities, they need more advanced and diverse technological knowledge to continuously develop their own technology. If searching for technological knowledge is limited in the home country, it is difficult to improve and to maintain their technology base continuously and it can lead to a loss of foreign markets for export. Therefore, export-oriented industries are eager to search and source the more advanced and diverse knowledge that exists in foreign countries. Moreover, based on their experiences in foreign countries, export-oriented industries have more opportunities to encounter potentially useful knowledge abroad.

Previous studies have investigated the effect of international trade on knowledge spillovers (Grossman & Helpman, 1991; Branstetter, 2001). When firms' export-intensities are high in the aggregate in an industry, familiarity and recognition of advanced foreign technological knowledge in an industry also increase. Export-oriented firms' foreign knowledge recognition can be shared and dispersed within their industry owing to spillover effects in the same industry. It naturally leads export-oriented industries to source knowledge internationally. In contrast, if an industry is more domestically-oriented, firms in the domestically-oriented industry have a restricted search for foreign knowledge resources as they have a fewer opportunities to encounter foreign knowledge resources. Thus, export-oriented industries tend to source knowledge internationally since they have a greater recognition and familiarity with advanced and diverse foreign technological knowledge. Moreover, export-oriented industries with a stronger technological knowledge base than domestically-oriented industries have a greater motivation to source advanced knowledge from foreign locations to maintain their leading technological position and to develop their technology further. Accordingly, we propose our first hypothesis as follow:

Hypothesis 1: The more export-oriented an industry is, the more likely it is to source knowledge internationally.

Inward FDI and international knowledge sourcing

Existing research on knowledge spillovers is suggestive of the importance of interaction between actors, such as firms, universities or government R&D centers in the same location (Jaffe et al., 1993; Griliches & Hjorth-Andersen, 1992; Maurseth & Verspagen, 2002). Knowledge diffusion increases when the interaction between actors in close proximity because knowledge is partially tacit. The actors are more likely to know and understand products and the technology of the other parties when they interact with one another in the same location (Cantwell & Santangelo, 1999). The interaction may be not just direct interaction such as cooperation or competition between firms, but also indirect interaction such as impact of FDI to local firms in an industry.

Theoretical and empirical research provides evidence that FDI is one of primary channels for knowledge spillovers (Blomstrom & Kokko, 1998; Xu, 2000; Liu & Wang, 2003; Sinani & Meyer, 2004). Branstetter (2006) demonstrates that FDI conduct an important role for knowledge spillovers in a bilateral way between investing firms and indigenous firms. Meyer and Sinani (2009) suggest that FDI may provide positive spillovers but its effect can be different in term of institutional framework, human capital and country's level of development. In fact, the impact of inward FDI is not limited to direct knowledge spillovers. Once the interactions occur through FDI, then the recognition and familiarity of foreign knowledge also increases. The inflow of foreign direct investment in an industry of the home country naturally helps firms in the same industry to recognize various foreign products and technologies. If the knowledge is diffused with some recognition as to the source of the knowledge, then firms in the home country are more likely to source knowledge from the foreign locations concerned because they recognize those foreign locations as potential knowledge sources. Since firms in the home country are able to identify from where the knowledge came, and they know from where the diverse knowledge originated, they become more familiar with the foreign source. This familiarity with foreign sources increases knowledge sourcing of firms in the home country internationally and creates more opportunities to obtain diverse technology from the foreign countries. Thus, if an industry receives more inward FDI, firms in the home country are more likely to source knowledge from foreign countries because they become more familiar with foreign knowledge resources and are able to access a more diverse range of technology that exists internationally. Hence, the following hypothesis is developed:

Hypothesis 2: The more inward FDI an industry receives, the more likely it is to source knowledge internationally.

So far, we have discussed how the degree of export-intensity and of inward FDI in an industry can influence its international knowledge sourcing. In what follows, we turn our attention instead to local knowledge sourcing in the home country. By only considering knowledge sourcing within the home country, we can investigate the relationships between Korean industries and their intra- or inter- industry patterns of knowledge sourcing locally.

Export and intra- vs. inter-industry knowledge sourcing in the home country

As we discussed in Hypothesis 1, export-oriented industries have more international connectedness than domestic-oriented industries. International connectedness through exporting can be beneficial to export-oriented industries in at least two ways in terms of technological knowledge. One is that export-oriented industries can learn more about foreign countries (Salomon & Shaver, 2005). They can be more familiar with diverse and advanced technological knowledge in foreign countries. The other is that export-oriented industries have more competition with competitors in foreign countries. This might be a difficult situation for export-oriented industries in the short term, but the firms of these industries may develop enhanced capabilities through being under more intense competitive pressures. By sourcing necessary technological knowledge from abroad and competing with competitors in foreign countries, export-oriented industries are likely associated with higher rates of internal capability development. On the other hand, if an industry is more domestically-oriented, an industry becomes less internationally connected due to a lack of exporting experience. Moreover, domestically-oriented industries generally face less competition because they serve fewer foreign markets. Therefore, domestically-oriented industries' internal capabilities tend to be relatively weaker than export-oriented industries.

So, what patterns of knowledge sourcing can be observed when industries engage in local knowledge sourcing? A lack of international connectedness and a low level of internal capabilities make it difficult for domestically-oriented industries to source knowledge from abroad compared to export-oriented industries. Instead, domestically-oriented industries depend upon export-oriented industries in the home country. Since knowledge sourcing abroad is limited and export-oriented industries have higher internal capabilities, domestically-oriented industries tend to engage in intra-industry knowledge sourcing from export-oriented industries. In contrast, export-oriented industries already possess high level of internal capabilities. They can source knowledge from the same industries, export-oriented industries themselves, rather than domestic-oriented industries that possess relatively weak knowledge. Thus, we propose a third hypothesis:

Hypothesis 3: The more export-oriented an industry is, the more likely it is to engage in intra-industry knowledge sourcing in the home country.

Inward FDI and intra- vs. inter-industry knowledge sourcing in the home country

Through Hypothesis 1 and Hypothesis 3, we have argued that exporting can play important roles for international connectedness and higher competitiveness. Similar arguments can be applied to inward FDI, and inward FDI can bring both the benefits of international connectedness and competitive pressure to industries.

When an industry receives FDI, the industry may acquire capabilities through international connectedness. Such on industry can recognize and use advanced resources that is available from foreign countries, such as capital, technological knowledge and innovation processes (Aitken & Harrison, 1999). By accessing and using those advanced resources, the industry can become more capable. Of course, it is possible that an industry with more capabilities may be a target location for inward FDI by foreign actors. The more capable an industry is, the more inward FDI the industry receives. Even in this case, the industry in question can be further developed and more capable from the benefits of inward FDI (Liang, 2017). Another benefit of inward FDI to an industry is that it can bring competitive pressures. Under more intense competition, firms in the industry are more likely to invest in capability development and in-house innovation to survive and be successful. As an industry sources knowledge from abroad to get necessary and more advanced technological knowledge, the relevant industry has stronger internal capabilities and accumulates higher technological knowledge stocks. Therefore, an industry with more inward FDI is more likely to search and source technological knowledge from the same industry to enjoy the benefits of high capabilities and technological knowledge stocks from within the local industry.

Instead, an industry with a low level of inward FDI cannot enjoy the benefits of international connectedness and competitive pressures. The industry relatively has a low level of international connectedness and lower competitive pressure due to a lack of inward FDI. In this case, an industry with lower inward FDI has relatively fewer opportunities to access and use advanced knowledge in foreign countries, and in turn, that industry's internal capabilities and technological knowledge stocks are also likely to be relatively weak compared to industries with more inward FDI. Since such an industry has only weak internal capabilities and technological knowledge stocks, it is more likely to source knowledge from industries with more inward FDI to access better resources in the case of local knowledge sourcing. Hence, we hypothesize as follows:

Hypothesis 4: The more inward FDI an industry receives, the more likely it is to engage in intra-industry knowledge sourcing in the home country.

5.3. Methods

5.3.1. Data

This study investigates how the relative openness of Korean industries affects their knowledge sourcing decision internationally and domestically. To test our hypotheses, we use data on patents granted in the US but invented in South Korea and their citations to earlier patents (knowledge sources). A patent document contains the location of the inventor(s), assignee firm information, technological classification, and citations to other earlier patents. Even though knowledge flows are not visible, patent citations provide information on how new technological knowledge develops on existing knowledge (Singh, 2005). Therefore, many studies have used patent citations to measure patterns of knowledge flows and sourcing (Almeida, 1996; Cantwell & Mudambi, 2011; Frost, 2001; Song et al., 2011).

Our patent sample derives from a database of USPTO patenting of South Korean origin with corporate assignees that have more than five patents between 2005 and 2013. By using the 56 technological fields classification, USPTO classifications of all the patents in our sample are regrouped. Since our study concerns issues of whether knowledge flows are intra-industry or inter-industry, the 56 technological fields need to be matched with industries. Therefore, we classify the primary technological fields of each industry as shown in Table 6 in the section 3.3. As we did in Study 1, we specify a 3-year lag between the year of the IVs (an industry's export-intensity and its annual level of investment by foreign capital) and the year of the citing patent in the DV. Thus, the data on an industry's export-intensity and its annual level of investment by foreign capital between 2002 and 2010 was obtained from Industrial Statistics Analysis System website operated by Korea Institute for industrial Economics and Trade, and the Ministry of Trade, Industry and Energy of South Korea respectively.

5.3.2. Variables and measures

5.3.2.1. Dependent variables

International knowledge sourcing. The same in Study 1, international knowledge sourcing is defined as use of patent invented in foreign countries. In order to measure this, we use the first named inventor location of cited patents. When a cited patent was invented in a foreign country, we construct a dummy variable for international knowledge sourcing that takes a value of 1. Otherwise, we code it as equal to 0. Allowing for a 3-year lag between the year of the citing patent in this variable which is our DV and the year of the IVs, this indicates the likelihood of international knowledge sourcing yearly from citing patents granted between 2005 and 2013. The share of domestic vs. international knowledge sourcing by citing patents between 2005 and 2013 is shown in Appendix 5.

*Intra-industry knowledge sourcing***.** Intra-industry knowledge sourcing is operationalized by the focal patent's citations of patents within the same industry. We code an observation as 1 if a technological field of cited patent belongs to the same industry as citing patent of a firm, and 0 if not. Allowing for a 3-year lag between the year of the citing patent in the DV and the year of the IVs, this indicates the likelihood of inter-field knowledge sourcing yearly from citing patents granted between 2005 and 2013. The share of intra- vs. inter-industry knowledge sourcing by citing patents between 2005 and 2013 is shown in Appendix 6.

5.3.2.2. Independent variables

Two independent variables, export-intensity of an industry and inward FDI of an industry, are considered to proxy the relative openness of an industry.

Export-intensity of an industry. The degree of export-intensity of an industry is operationalized by the ratio of total exports to total sales in each industry and in each year from 2002 to 2010. This is a widely used measurement in management and international business research (Majocchi, Bacchiocchi, & Mayrhofer, 2005; Boehe & Jimenez, 2016).

$$\text{Export-intensity of an industry} = E_{ij}$$

Where E_{ij} is export-intensity in an industry i (i = 1, . . . , 16) in a given year j (j = 1, . . . , 9).

*Inward FDI of an industry***.** To analyze the influence of inward FDI on each industry of South Korea, we also need to look at the intensity of investment in an industry, not the absolute volume of inward FDI in each industry. The size and the level of activities in each industry should be considered together. Thus, the share of inward FDI in each industry can be measured by the ratio of the total volume of inward FDI to the total level of all investment in each industry and in each year from 2002 to 2010.

$$\text{Inward FDI of an industry} = F_{ij}$$

Where F_{ij} is inward FDI in an industry i (i = 1, . . . , 16) in a given year j (j = 1, . . . , 9).

5.3.2.3. Control variables

Korea's level of comparative technological development. Korea's level of comparative technological development, which is the primary independent variable in

Study 1 is included as a control variable in Study 2. The changes in Korea's technological development may influence intra- vs. inter-industry knowledge sourcing in Korea as well as international knowledge sourcing. Thus, in order to control for this possibility, Korea's technological development is included when testing all the Hypotheses in Study 2.

Korean knowledge stock. Prior capabilities in the relevant field in South Korea may be alternative knowledge resources instead of knowledge from foreign locations. Thus, the accumulated Korean knowledge stock needs to be allowed for in a more accurate analysis. The knowledge stock in South Korea is measured by the share of Korean invented cited patents in each of the 56 technological fields.

Knowledge stock of foreign-owned firms in South Korea. Since our sample covers all patents invented in South Korea, patents invented by foreign-owned firms in South Korea are also included. Even though the percentage of patents by foreign-owned firms in our data is very low (around 6%), there might be some effect from foreign-owned firms' citing patents on international knowledge sourcing. Therefore, we include the accumulated knowledge stock of foreign-owned firms in South Korea as a control variable. It is coded "1" if patents were invented by a foreign-owned firm in South Korea and "0" if the patents were invented by Korean firms in South Korea.

5.3.3. Samples and model

Our sample is composed of 472,303 observations for Hypothesis 1 and Hypothesis 2 to analyze the effects of relative openness of an industry and its knowledge sourcing abroad. For Hypothesis 3 and Hypothesis 4, we consider only the 66,065 Korean-invented citations to analyze the patterns of local knowledge sourcing under the impact of the relative openness of an industry. The dependent variables, international knowledge sourcing and intra-industry knowledge sourcing, are binary variables in count form. Therefore, as discussed in methods section in the Study 1, we employ a negative binomial regression to investigate the effects of relative market openness on both knowledge sourcing abroad and intra-industry knowledge sourcing in the home country in this study

5.4. Results

Table 11 shows descriptive statistics for all the variables included in the model. The correlation matrix of variables for Hypothesis 1 and Hypothesis 2 are reported in Table 12 and variables for Hypothesis 3 and Hypothesis 4 are presented in Table 13. Even though interpreting the size of a correlation coefficient does not follow a specific criterion, in general, there is no multi-collinearity issues if absolute value of the correlation coefficient is less than 0.5. In Table 12 and Table 13, there are no variables that are higher than 0.5. Thus, we do not have a multi-collinearity problem in our data.

Table 11. Summary of descriptive statistics

Variable		Mean	Std. Dev.	Min	Max
1	International knowledge sourcing	0.8541	0.3530	0	1
2	Intra-industry knowledge sourcing	0.9496	0.2187	0	1
3	Korea’s level of comparative technological development	15.2291	15.5766	0	62.43

4	Korean knowledge stock	13.7325	3.5374	0	17.4
5	Knowledge stock by foreign-owned firms in South Korea	0.0663	0.2489	0	1
6	Export-intensity	40.2759	5.2894	1.38	74.32
7	Inward FDI	2.5096	0.6951	0	6.19

Table 12. Correlations for variables for H1 & H2

	Variable	1	2	3	4	5	6
1	International knowledge sourcing	1.000					
2	Korea's level of comparative technological development	-0.021	1.000				
3	Korean knowledge stock	-0.101	0.193	1.000			
4	Knowledge stock of foreign-owned firms in South Korea	0.034	0.369	-0.010	1.000		
5	Export-intensity	0.032	-0.006	-0.060	-0.018	1.000	
6	Inward FDI	0.033	-0.039	-0.106	-0.060	0.430	1.000

N = 472,303

Table 13. Correlations for variables for H3 & H4

	Variable	1	2	3	4	5	6
1	Intra-industry knowledge sourcing	1.000					
2	Korea's level of comparative technological development	0.060	1.000				
3	Korean knowledge stock	0.043	0.178	1.000			
4	Knowledge stock of foreign-	-0.051	0.336	0.006	1.000		

	owned firms in South Korea							
5	Export-intensity	0.048	0.021	-0.018	-0.062	1.000		
6	Inward FDI	0.050	-0.001	-0.026	-0.059	0.406	1.000	

N = 66,065

Table 14 presents the results of negative binomial regression models in which the dependent variable is international knowledge sourcing in the case of Hypothesis 1 and Hypothesis 2. Model 1 in the Table 14 includes control variables; the Korean knowledge stock and the knowledge stock of foreign-owned firms in South Korea. An export-intensity variable is included in Model 2 as we propose a hypothesis that there are positive relations between export-intensity in an industry and its international knowledge sourcing. Model 3 tests the effects of inward FDI in an industry on its international knowledge sourcing. Model 4 includes all the same control and independent variables as in the full model.

In Model 1, the coefficient estimate for the Korea's level of comparative technological development and the Korean knowledge stock are negative and significant. The coefficient on knowledge stock by foreign-owned firms in South Korea is significant and positive. The coefficient on export-intensity in Model 2 is positive and significant (Model 2: $\beta = 0.002$, $p < 0.01$). This suggests that an industry with higher export-intensity is more likely to source knowledge internationally, providing support to Hypothesis 1. Model 3 examines Hypothesis 2 that predicts a positive relationship between inward FDI in an industry and knowledge sourcing abroad. The coefficient estimates for inward FDI is positive and significant (Model 3: $\beta = 0.014$, $p < 0.01$). This result suggests that an industry with higher inward FDI is more likely to source knowledge abroad, supporting

Hypothesis 2. We can confirm that the effects of both export-intensity and inward FDI on international knowledge sourcing show consistent results in our full model, Model 4.

Table 14. Negative binomial regression models of international knowledge sourcing

DV: International knowledge sourcing	Model			
	1	2	3	4
Korea's level of comparative technological development	-0.000 (0.000)***	-0.000 (0.000)***	-0.000 (0.000)***	-0.000 (0.000)***
Korean knowledge stock	-0.011 (0.000)***	-0.010 (0.000)***	-0.010 (0.000)***	-0.010 (0.000)***
Knowledge stock of foreign-owned firms in South Korea	0.063 (0.007)***	0.064 (0.007)***	0.065 (0.006)***	0.065 (0.007)***
Export-intensity		0.002 (0.000)***		0.002 (0.000)***
Inward FDI			0.014 (0.002)***	0.009 (0.002)***
Observations	472,303	472,303	472,303	472,303
Log likelihood	782.95	830.24	821.38	843.38

*p < 0.10, **p < 0.05; *** p < 0.01.

Table 15 shows the results for Hypothesis 3 and Hypothesis 4. We run negative binomial regression models with a dependent variable, intra- vs. inter-industry knowledge sourcing within South Korea. Model 1 in Table 15 shows the results of all the control variables. Model 2 examines the effects of export-intensity on intra-industry knowledge sourcing locally. The inward FDI variable is included in Model 3 as we propose a hypothesis that there are positive association between inward FDI in an industry and the degree of intra-industry knowledge sourcing within South Korea. We include both independent variables in Model 4.

Model 2 tests Hypothesis 3, which supposes the existence of positive effects of export-intensity on the intra-industry knowledge sourcing locally. The coefficient of export-intensity is positive and significant (Model 1: $\beta = 0.003$, $p < 0.01$), providing support to Hypothesis 3. This shows that export-oriented industries are more likely to engage in intra-industry knowledge sourcing than domestically-oriented industries within the home country. In Model 3, results for the effects of inward FDI are presented. The relationship between inward FDI and intra-industry knowledge sourcing are positive and significant (Model 2: $\beta = 0.027$, $p < 0.01$). Thus, Hypothesis 4 is also supported. Those results are confirmed again in our full model (Model 4). Figures for the results of all Hypotheses in Study 2 are included as Appendix A7, A8, A9 and A10.

Table 15. Negative binomial regression models of intra- vs. inter-industry knowledge sourcing

DV: Intra-industry knowledge sourcing	Model			
	1	2	3	4
Korea's level of comparative technological development	0.001 (0.000)***	0.001 (0.000)***	0.001 (0.000)***	0.001 (0.000)***
Korean knowledge stock	0.003 (0.002)*	0.003 (0.002)*	0.003 (0.002)*	0.003 (0.002)*
Knowledge stock of foreign-owned firms in South Korea	-0.087 (0.021)***	-0.083 (0.021)***	-0.084 (0.021)***	0.082 (0.021)***
Export-intensity		0.003 (0.001)***		0.002 (0.001)*
Inward FDI			0.027 (0.001)***	0.019 (0.011)*
Observations	472,303	472,303	472,303	472,303

Log likelihood	33.63	39.90	40.78	42.82

*p < 0.10, **p < 0.05; *** p < 0.01.

As in Study 1, we provide the estimates of linear effects for each pair of independent variable and dependent variable in each Hypothesis, to analyze the effect sizes of our results. *We find that as the export-intensity of an industry changes, 1) around a 16% change (between 77% and 93%) in international knowledge sourcing (Figure 10), 2) around a 10% change (between 81% and 91%) in intra-industry knowledge sourcing within Korea (Figure 12). In the case of inward FDI, as inward FDI in an industry changes, 1) around a 10% change (between 81% and 91%) in International knowledge sourcing (Figure 11), and 4) around a 14% change (between 80% and 94%) in intra-industry knowledge sourcing within Korea (Figure 13).*

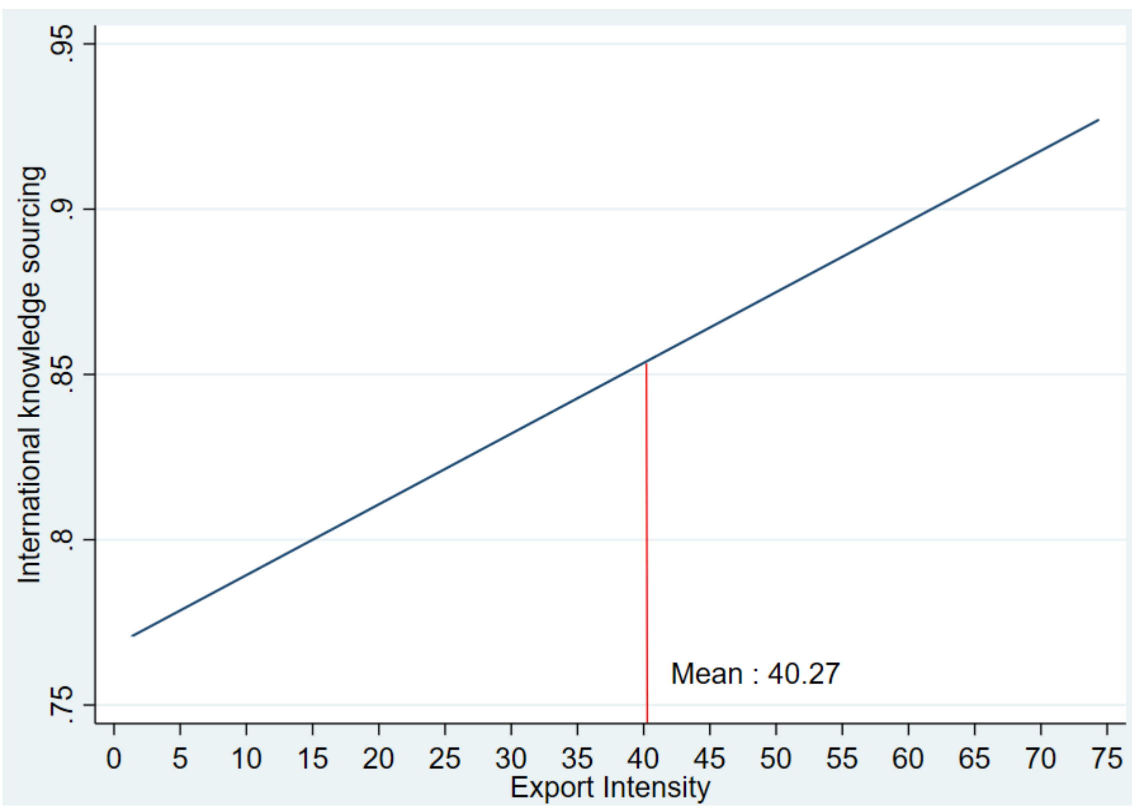

Figure 10. Effect size of export intensity of an industry on international knowledge sourcing

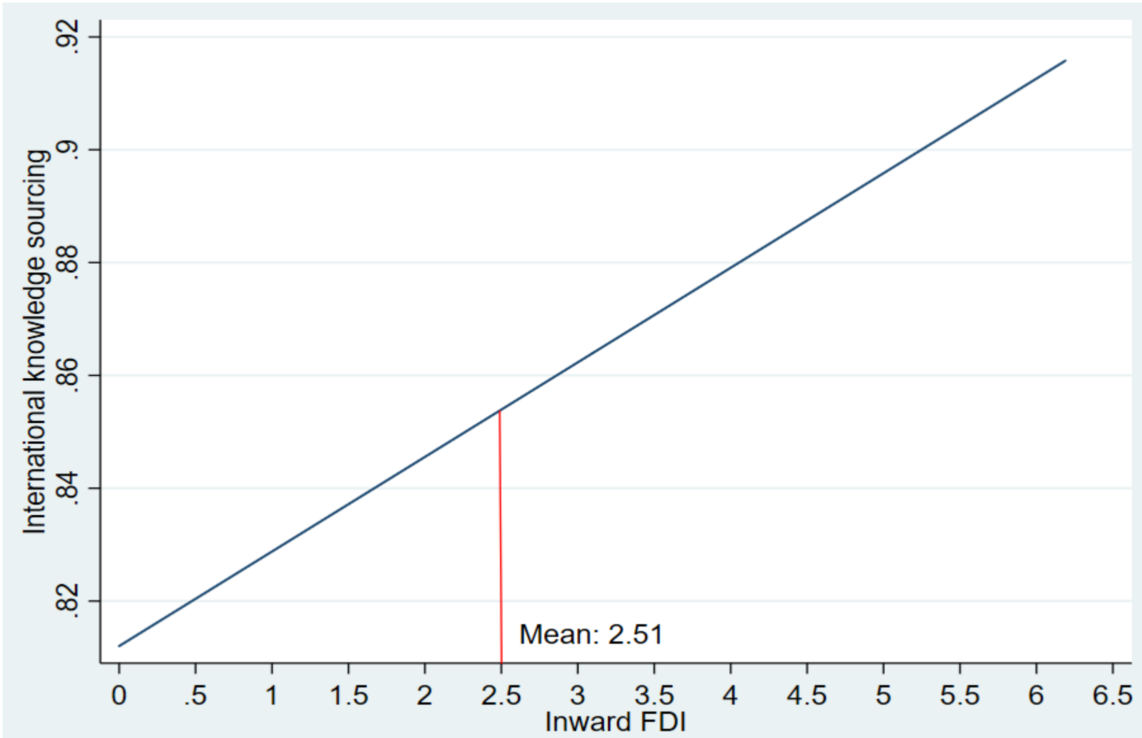

Figure 11. Effect size of inward FDI in an industry on international knowledge sourcing

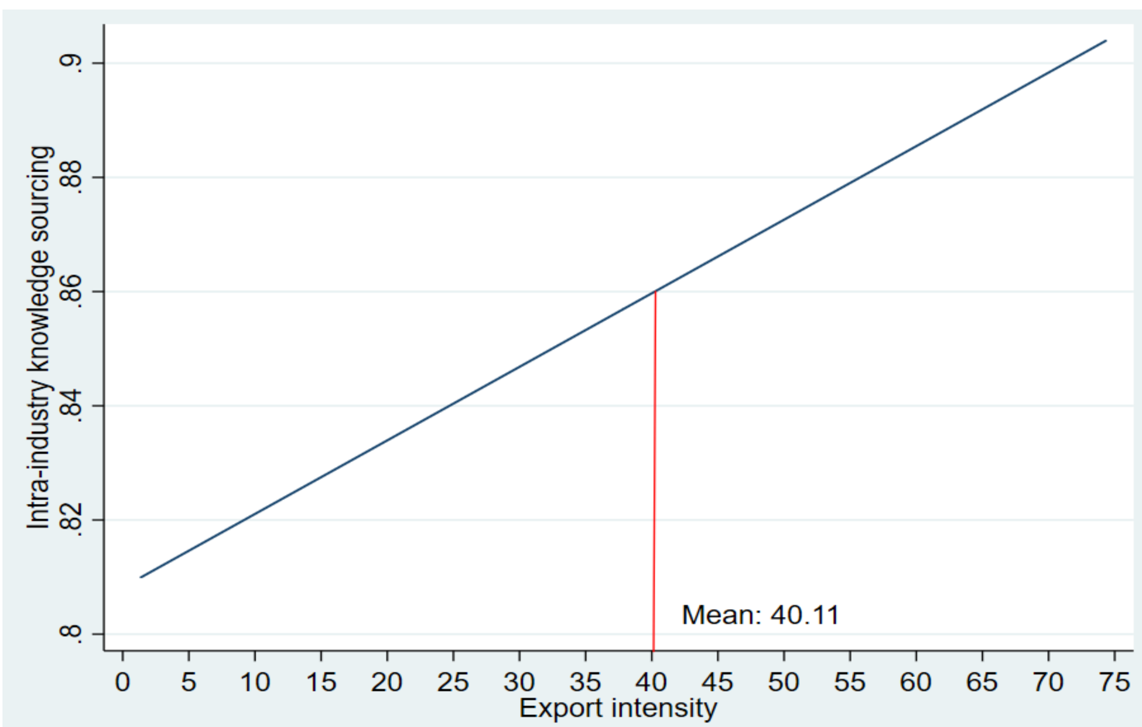

Figure 12. Effect size of export intensity of an industry on intra-industry knowledge sourcing within Korea

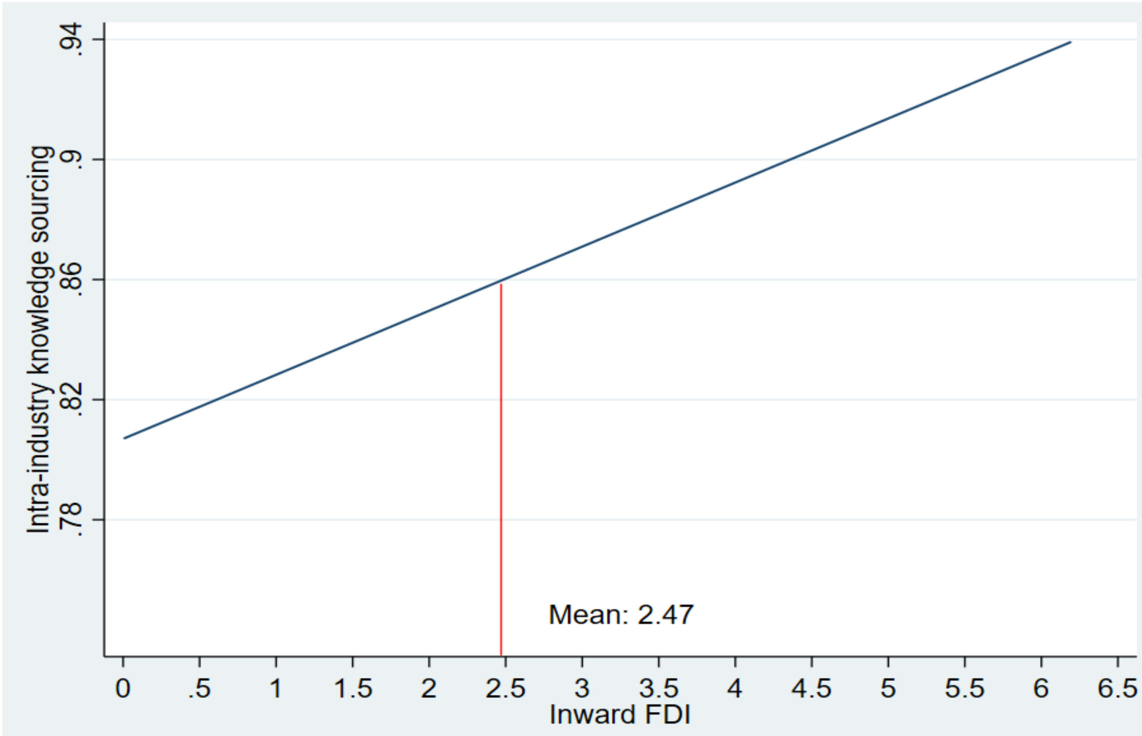

Figure 13. Effect size of inward FDI in an industry on intra-industry knowledge sourcing within Korea

5.5. Discussion

Our results from negative binomial regressions show that the export-intensity and inward FDI of an industry have a positive association with the international knowledge sourcing of firms in an industry (Hypotheses 1 & 2). The results suggest that both exports and inward FDI can play critical roles for knowledge sourcing from abroad by opening an industry to foreign business relationships and so by having more potential international connections. Exporting activities help firms to recognize and access new technological knowledge that can only be obtained in certain foreign countries. Inward FDI can bring more interactions with foreign resources and knowledge in the given industry. In other words, exporting activities in foreign countries and interactions with foreign resources in an industry of the home country through inward FDI can help firms in an industry become aware of more foreign technological knowledge that they can use in their own knowledge development. As firms in an industry with greater export intensity and more inward FDI become more connected to foreign contacts and resources, they have more opportunities to access diverse and advanced technological knowledge, and, in turn, to source the technological knowledge more actively from the foreign countries.

We also observe the impact of export-intensity and inward FDI on local knowledge sourcing through Hypotheses 3 and 4. Export-oriented industries and industries with more inward FDI tend to possess higher capabilities associated with their international connectedness. Those industries lead to have more opportunities to source advanced technological knowledge from foreign countries and to build strong capabilities through being in more active competition with foreign firms. Thus, an industry with more exporting activities and more inward FDI tends to engage in intra-industry knowledge sourcing locally because it is now able to exploit the more munificent technological knowledge stocks that have been built up in its own industry at home. Domestically-oriented industries, however, have a lack of connection to foreign countries, and it makes them difficult to source knowledge internationally. This is associated with a lower level of international capabilities. Since there are only weaker technological knowledge stocks that have been accumulated at home in their own industry, domestically-oriented industries are more likely to instead rely upon inter-industry knowledge sourcing, by exploiting knowledge from other industries with higher internal capabilities, such as more export-oriented industries or industries with higher inward FDI.

These findings suggest two important implications. First, this study shows how international knowledge sourcing through international connectedness, accumulation of technological capabilities and intra-industry knowledge sourcing within the home country are interconnected in an industry. International connectedness through the openness of an industry can play important roles in facilitating knowledge flows and knowledge development. International connectedness through exports and inward FDI is critical because it provides a more extensive basis on which to source knowledge dispersed around the world, and so to accumulate stronger technological capabilities in local industries. In this process, international knowledge sourcing influences local knowledge-sourcing behavior. Industries can source more technological knowledge from foreign countries through more international connectedness, and it leads an accumulation of stronger technological capabilities in their industries, which in turn, influences the propensity to source knowledge from their own industry as a source rather than as a recipient.

Another important implication of this study is to help explain the emergence of two different paths of knowledge sourcing patterns when comparing outer-focused industries and inner-dependent industries, and the consequent pattern of knowledge-based relationships between the industries in terms of knowledge flows within the home country. Outer-focused industries, which have a greater export intensity and more inward FDI, are more likely to source knowledge internationally and internally from within their own industries in order to continuously upgrade their technological capabilities. However, Inner-dependent industries, which have a lesser export intensity and inward FDI, are more likely to source knowledge locally than internationally and to rely on their absorption of knowledge from other industries. This is because inner-dependent industries are less able to engage directly in international knowledge sourcing than are outer-focused industries. Inner-dependent industries draw upon the superior technological knowledge of outer-focused industries in order to catch up. Through local knowledge sourcing from outer-focused industries, inner-dependent industries may be able to accumulate technological knowledge and potentially also to thereby open an indirect door to for international knowledge sourcing. In other words, outer-focused industries can be a domestic pathway or connector to foreign knowledge resources. Thus, this study shows knowledge development in the Korean case through international knowledge sourcing by outer-focused industries, and knowledge development through local knowledge sourcing from outer-focused industries by inner-dependent industries.

6. Conclusions

This dissertation research attempts to find the determinants of the knowledge sourcing behaviors of Korean firms in a home country characterized by weak internationalization of R&D. Knowledge sourcing is one of the most important factors in firms' technological development and innovation. Recently, knowledge sourcing has become more important because technologies have become more complex and they are changing very fast. Thus, firms are more likely to source knowledge from foreign countries to search and obtain diverse and more advanced knowledge. Although recent studies have paid attention to the importance of international knowledge sourcing, they have mainly focused on the role of subsidiaries in foreign countries for knowledge sourcing and knowledge transfer through internal MNC networks. However, knowledge exchange between parents and subsidiaries is not critical in some countries such as South Korea, and yet they have still successfully developed their technological capabilities in the home country using several channels to access knowledge other than subsidiaries in foreign countries. Thus, we investigate what conditions influence the knowledge sourcing of Korean firms in this dissertation. The impact of country level conditions on Korean firms' knowledge sourcing behavior is studied in Study 1, and the effects of industry level conditions are investigated in Study 2.

In Study 1, we analyze the impact of Korea's comparative technological development on Korean firms' international knowledge sourcing, its degree of technological field dispersion, and knowledge sourcing from foreign countries with traditionally rich technological knowledge resources. We find that there is a U-shaped relationship between Korea's level of comparative technological development and international knowledge sourcing. Also, in general, Korea's comparative technological development is positively associated with Korean firms' inter-field international knowledge sourcing, but in the cases of high development fields, they tend to engage in intra-field international knowledge sourcing. For the relationship between Korea's level of comparative technological development and knowledge sourcing from foreign countries with traditionally richer knowledge resource, an inverted U-shaped relation is found. Finally, we find that economic and technological relationships are more important than geographic proximity on international knowledge sourcing as Korea's technologies develop further.

In Study 2, we investigate the impact of the relative openness of an industry on knowledge sourcing. By considering export-intensity and inward FDI in an industry, we examine how international connectedness through the relative openness of an industry can influence knowledge sourcing from abroad and knowledge sourcing locally. Our results suggest that relative openness and international connectedness can bring greater accessibility to foreign knowledge and so help in the accumulation of technological capabilities. Therefore, international economic linkages can be critical for exploiting knowledge dispersed throughout the world, and they may also influence intra- and inter-industry knowledge sourcing behavior in the home country.

6.1. Contributions

This research contributes to the literature of international knowledge sourcing. Prior studies have mainly emphasized the relationship between parents and their subsidiaries in international knowledge sourcing. However, Korean firms have successfully developed technological capabilities through a wider set of knowledge sourcing channels other than the technological activities of subsidiaries in foreign countries. Thus, this research can help to provide a more balanced perspective on knowledge sourcing by considering contexts that rely upon a broad spectrum of knowledge sourcing channels. Moreover, this study shows the importance of the openness and international connectedness of an industry in its knowledge flows. Our findings suggest that international connectedness is critical to access knowledge internationally and thereby to accumulate strong technological capabilities.

A practical implication of this study is to suggest a wider set of ideas and guidelines for international knowledge sourcing that may be more applicable for many countries. The issues illustrated in this paper are relevant and may be applicable especially for emerging markets. The public policy agenda may benefit from consideration of the issues discussed in this dissertation. Governments in many emerging economies such as many Latin and Asian countries have stressed their own firms becoming more global and international. To facilitate corporate globalization, governments need to develop appropriate policies. Emerging markets that need to catch up in advanced technologies have to consider the nature of the environments required build to foster the international knowledge sourcing of domestic firms.

Admittedly, every country has a different situation, so the issues examined in this dissertation might not be directly applicable in some other countries. Even in this case, this research can still provide one pillar for a comparison of different emerging markets. Therefore, this research can provide a good starting point for assessing why and how the knowledge sourcing behavior of firms from different countries are so different to each other.

6.2. Limitations and future research

Several future research directions can be derived from this dissertation. I investigated the impact of some country level and industry level factors on Korean firms' knowledge sourcing behavior. In future research, some firm level factors, such as a firm's technological capabilities or specialization can be also considered to analyze the knowledge sourcing behavior of firms located in Korea, which has had a weak internationalization of R&D.

In Hypotheses 2b of Study 1, we found that HDFs are more likely to engage in intra-field international knowledge sourcing. This may be an interesting point for further research. We would need to look at reciprocal citation (cross-country citation patterns) between Korea and other foreign locations in the HDFs oppose to other fields. If our arguments in the discussion section of that chapter are right, we should see a rise in intra-field citations in HDFs, and a higher proportion of intra-field citations should be observed between Korea and the rest of the world in both directions.

This dissertation has considered just one country, South Korea. Although Korea is a special case that has very weak internationalization of R&D, there are some other countries, such as Japan and Taiwan that have similar conditions. Thus, future comparative research can be conducted with Japan and Taiwan to access the generalizability of our findings in this research.

Finally, future scholarship might compare countries more widely in terms of the internationalization of their R&D and knowledge sourcing. The spread of R&D activities of European countries are very different from those of Korea. Korea's R&D activities and knowledge sourcing is also different from that of China and India. Also, there are variations even among European countries. It might be meaningful and interesting to compare and contrast the patterns of R&D activities and knowledge sourcing across several different categories of countries. If they show distinctive patterns and trends relative to one another, it might be interesting to deepen our understanding of why they are different.

7. References

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8. Appendices

Appendix A1 - The share of domestic/international knowledge sourcing by citing patents between 1984 and 2013 (5-year periods)

	1984-88	1989-93	1994-98	1999-2003	2004-08	2009-13	Total
International knowledge sourcing	995	8,799	43,269	108,414	175,195	317,675	654,347
Percent (%)	98.51	97.24	93.27	90.37	88.47	85.65	87.79
Domestic knowledge sourcing	15	250	3,121	11,551	22,832	53,233	91,002
Percent (%)	1.49	2.76	6.73	9.63	11.53	14.35	12.21

* On average, around 88% of knowledge is sourced from foreign locations.

* Share of international knowledge sourcing is decreasing over time.

Appendix A2 - The share of intra- vs. inter-field sourcing across 56 technology fields by citing patents between 1984 and 2013 in foreign countries (5-year periods)

	1984-88	1989-93	1994-98	1999-2003	2004-08	2009-13	Total
Inter-field sourcing	292	2,686	13,943	36,361	63,804	124,254	241,340
Percent (%)	29.35	30.53	32.22	33.54	36.42	39.11	36.88
Intra-field sourcing	703	6113	29,326	72,053	111,391	193,421	413,007
Percent (%)	70.65	69.47	67.78	66.46	63.58	60.89	63.12

* On average, around 37% of knowledge is engaged in inter-field sourcing internationally.

* Share of inter-field international knowledge sourcing is increasing over time.

Appendix A3 - The share of knowledge sourcing from top 4 foreign countries with traditionally richer technological knowledge resources vs from other foreign countries with citing patents between 1984 and 2013 (5-year periods)

	1984-88	1989-93	1994-98	1999-2003	2004-08	2009-13	Total
Top 4 foreign countries	272	3,800	20,662	44,719	73,811	126,388	269,652
Percent (%)	74.32	84.97	87.48	81.31	79.43	76.79	79.09
Other foreign countries	94	672	2,958	10,276	19,112	38,193	71,305
Percent (%)	25.68	15.03	12.52	18.69	20.57	23.21	20.91

* Around 79% of knowledge is sourced from top 4 foreign countries with traditionally richer technological knowledge resources.

Appendix A4 - The share of knowledge sourcing from Japan and other top 3 foreign countries with traditionally richer technological knowledge resources with citing patents between 1984 and 2013 (5-year periods)

	1984-88	1989-93	1994-98	1999-2003	2004-08	2009-13	Total
Top 3 foreign countries	87	812	3,107	6,670	9,761	19,528	39,965
Percent (%)	31.99	21.37	15.04	14.92	13.22	15.45	14.82
Japan	185	2,988	17,555	38,049	64,050	106,860	229,687
Percent (%)	68.01	78.63	84.96	85.08	86.78	84.55	85.18

* On average, around 85% of knowledge is sourced from Japan.

* In general, share of international knowledge sourcing from top 3 foreign countries

decrease over time.

Appendix A5 - The share of domestic vs. international knowledge sourcing by citing patents between 2005 and 2013 (3-year periods)

Periods	International knowledge sourcing	Domestic knowledge sourcing	Total
2005-2007	89,758 (87.65%)	12,648 (12.35%)	102,406 (100%)
2008-2010	143,486 (85.50%)	24,343 (14.50%)	167,829 (100%)
2011~2013	170, 146 (84.20%)	31,922 (15.80%)	202,068 (100%)
Total	403,390 (85.41%)	68,913 (14.59%)	472,303 (100%)

* Intra-industry knowledge sourcing incrementally increases.

Appendix A6 -The share of intra- vs. inter-industry knowledge sourcing within Korea by citing patents between 2005 and 2013 (3-year periods)

Periods	Inter-industry knowledge sourcing	Intra-industry knowledge sourcing	Total
2005-2007	11,590 (94.98%)	612 (5.02%)	12,202 (100%)
2008-2010	22,465 (95.82%)	978 (4.18%)	23,443 (100%)
2011~2013	28,682 (94.29%)	1,738 (5.71%)	30,420 (100%)
Total	62,737 (94.96%)	3,328 (5.04%)	66,065 (100%)