**Master's Thesis in Economics**

# Globalization of Innovation and National Innovation System (NIS): Evidence from Patent Data

**혁신 및 국가 혁신 시스템 (NIS)의 세계화 :**
**특허 데이터로부터의 증거**

**February 2019**

**Graduate School of Seoul National University**
**Department of Economics, Economics Major**
**Albertine June M. Din**

# Globalization of Innovation and National Innovation System (NIS): Evidence from Patent Data

**Academic advisor Lee Keun**

**Submitting a master's thesis of Economics**

**December 2018**

**Graduate School of Seoul National University**

**Economics Major**

**Albertine June Din**

**Confirming the master's thesis written by**

**Albertine June Din**

**January 2019**

| | | |
|---|---|---|
| Chair | Yi Sang-Seung | (Seal) |
| Vice Chair | Lee Keun | (Seal) |
| Examiner | Lee Jihong | (Seal) |

# Agreement on Original Contents Provision

Concerning my thesis, I agree that Seoul National University will provide it for the purpose of the following:

1. Matters Agreed Upon

①I agree on duplication of my thesis for the purpose of its preservation or online provision only if the contents are maintained as the original ones.

②I agree on digitalizing my thesis and reproducing/distributing, for internet or other communication networks, part of or the entire of the thesis for free of charge.

2. Author's Obligation

I will immediately notify the Graduate School of Seoul National University of a request for suspension or cancellation of public use of my thesis once any changes in the agreement are needed (such as transfer of copyright to a third party or approval of publication of my thesis).

3. Obligation of Seoul National University

①Seoul National University will use the copyright protection tool (DRM) in case that the university provides the thesis to external users.

②Seoul National University will take immediate follow-up actions once the author requests for a suspension or cancellation of public use of the thesis.

**Thesis Title:** Globalization of Innovation and National Innovation System (NIS): Evidence from Patent Data

Category of Degree: **Master's Thesis / · Doctoral Thesis** □

Department: Economics

Student ID.: 2016-24529

Contact Number: +82-10-2573-9406

Author: Albertine June Din (Seal)

Date of submission: December 20, 2018

# Abstract

## Globalization of R&D and economic growth: patent evidence from East Asia

Albertine June Din
Department of Economics
The Graduate School
Seoul National University

This study examines the trend of globalization of R&D in East Asia (Korea, Taiwan and China) and its dynamics with their respective National Innovation Systems (NIS) from 1980 to 2010 using patent data of firms from COMETS 2.0. Globalization of R&D is composed of inbound R&D and outbound R&D. Inbound R&D is the presence of research activities and facilities within a country's borders owned by foreign firms. On the other hand, outbound R&D are the research activities conducted by local firms abroad. With the focus on the impact of globalization of R&D to the development of NIS, this study uses patent data to measure inbound and outbound R&D. In other words, inbound R&D is measured by patents owned by foreign assignees but invented locally, while outbound R&D is measured by patents owned by local assignees but invented abroad.

There are two parts in this paper. The first part answers the first research question, *do the trends between inbound and outbound R&D reflect the FDI flows in China, Korea and Taiwan?* This was answered by examining at the sequencing of inbound and outbound R&D in the three countries. The results show a similarity with the trend of the respective FDI flows of each country. Borrowing the reasoning from investment development path (IDP) theory, the successful catch-up countries of Korea and Taiwan saw a convergence of their inbound R&D and outbound R&D as their economies developed. Particularly, inbound R&D came first at the earlier stages of growth, and at the later stages of economic growth, the outbound R&D grew at a faster rate and exceeded the trend of their respective inbound R&D.

The second part of the paper aimed to answer the second and third research questions: (2) *how does inbound R&D relate with the NIS variables in Korea and Taiwan*; and (3) *how does outbound R&D relate with the NIS variables in Korea and Taiwan.* Empirical tests were conducted based on the stationarity of the variables. Specifically, for both I(0) variables, Vector Autoregression (VAR) was used; for both I(1) variables, the Johansen Cointegration Test and Vector Error Correction Model (VECM) were used; and for bivariate equations with a mix of I(0) and I(1) variables, Autoregressive

Distributed Lag (ARDL) model was used. The results show robust results in the following long-run relationships: (1) previous inbound R&D variables helping predict current values of the localization of knowledge creation, (2) localization of knowledge creation influencing the amount of locally assigned patents, and (3) localization of knowledge creation influencing outbound R&D.

**Key words:** globalization of R&D, inbound R&D, outbound R&D, national innovation system, VAR, VECM, ARDL

**Student number:** 2016-24529

**Table of Contents**

**List of tables**

**List of figures**

# I. INTRODUCTION

## 1. Innovation and technology in economic theory

The increasing attention given to the Fourth Industrial Revolution reflects the wide acceptance of technology as one of the major determinants of economic growth. While the neoclassical economists in the early half of the 20th century identified technological growth as a source of economic growth by addressing the declining marginal product of capital, their works have treated technological change as a "black box"—an exogenous to the economic growth model. A significant turn from this view is the effort to "endogenize" technological change, starting from the works of Romer (1986) and Lucas (1988), which started the new growth theory (Guloglu & Tekin, 2012). Various economists have studied innovation as a source of economic growth, including Joseph Schumpeter's creative destruction and Paul Romer's ENDOGENOUS growth. Innovation, referring to inventions with economic value, is particularly viewed in relation with economic growth, given its direct relation with increasing productivity. As such, the relevant question for catching up economies especially at the wake the Fourth Industrial Revolution is how to instigate innovation and improve their national innovation systems in order to pursue competitiveness, and eventually economic growth or catch-up.

One of the answers from the literature is by accessing foreign knowledge. In particular, the dynamics of foreign direct investment (FDI) in Asia shows that emerging countries in the late 20th century showed initially rising FDI inflow, followed by a rising outflow (Alvstam, Dolles and Strom, 2014). This shows that countries such as South Korea (hereafter Korea) and Taiwan received and sent out FDI. Investments abroad have different objectives: those seeking for natural resources, markets, efficiency, and strategic assets. Examples of strategic assets that can be acquired through FDI are knowledge and technology. As such, parallel to the concepts of FDI inflow and outflow, there is a concept of inbound R&D and outbound R&D.

## 2. Foreign direct investments in Korea, Taiwan and China

The Asian Tigers (which includes South Korea and Taiwan) generally followed the IDP model, where the level of economic development and the specific advantages of their firms allowed for the growth of their outward investments (Alvstam, Dolles, Ström, 2014). An initially higher inflow of FDI followed by rising FDI outflow were observed in the early period in Taiwan and South Korea. However, in the earlier years in the 1950s, East Asian countries have adopted infant industry programs that also limited foreign ownership. With the aim to build manufacturing capabilities, Taiwan changed its import substituting regime in the late 1950s, while Korea did the same in the mid-1960s.

Their governments shifted to export-oriented industrialization, and the policies of these two countries have guided both inward and outward foreign investments to specific developmental ends, marrying the FDI policies and the industrial policy to 'strategic industrial policy' (Thurbon and Weiss, 2006).

*Korea*

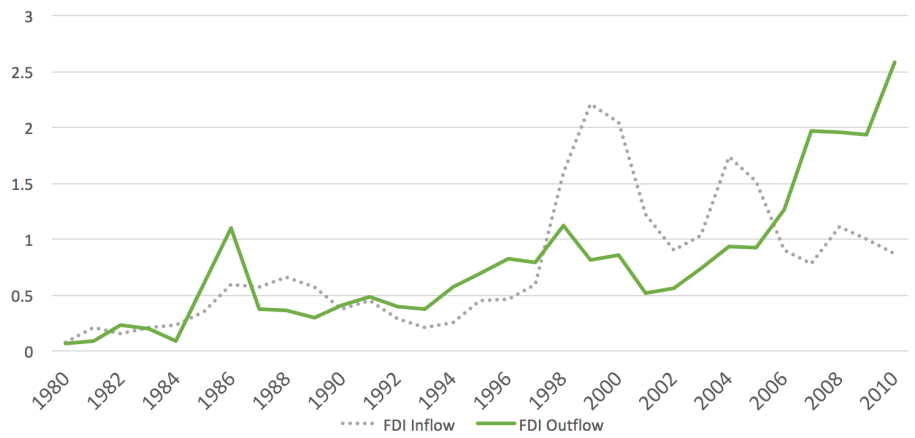
Two conflicting concerns shaped Korea's FDI policy: trauma from foreign domination after a century of Japanese colonialism, and need for capital (Thurbon and Weiss, 2006). Consequently, foreign borrowing had a larger share in the capital inflows in Korea in comparison with FDI, and with the limited FDI allowed inside the country, they were heavily regulated. This control of driving FDI towards developmental plans was the responsibility of the Economic Planning Board (EPB) established in 1961

As can be seen in Figure 3, FDI inflow in Korea shows cycles, but generally a decreasing trend since the 1990s. FDI inflow took an upturn after the Financial Crisis, when the government was forced to open up their capital market. On the other hand, their FDI outflow shows a generally upward trend. By 2005, the share of outflow has become higher than their FDI inflow.

In response to the 1997 Asian Financial Crisis, Korean firms (chaebols) were forced to restructure their companies to survive. One such restructuring was in the Samsung Group, where the then chairman Lee Kun-Hee divested the

newly started Samsung Automobile Co. Ltd to Renault (a French automobile company) in 2000 (forming the Renault Samsung Motors Co., Ltd), and sold the Samsung Heavy Equipment Co. Ltd to Volvo (a Swedish company) in 1998. The latter deal amounted around US$ 700 million, becoming the largest inward FDI in South Korea at that time (Park, Alvstam, Dolles and Ström, 2014).

**Figure 1. FDI flows in Korea as % of GDP, 1980-2010**



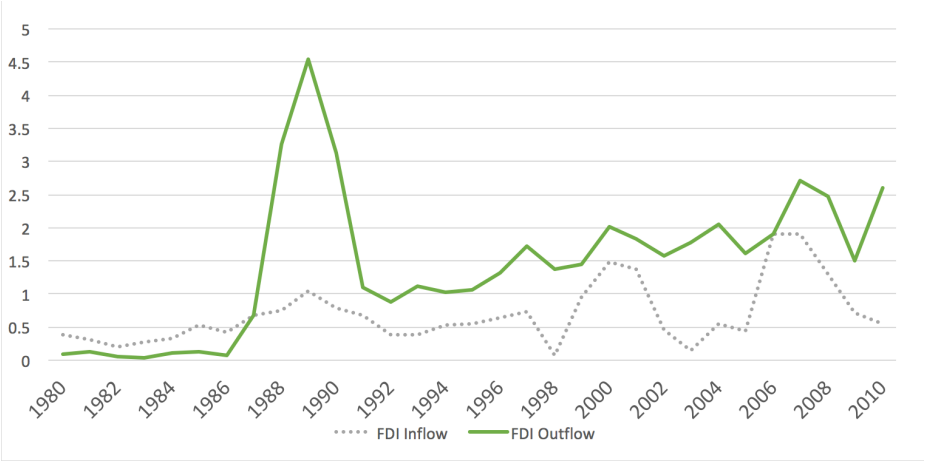

*Data Source: UNCTAD*

Lee and Plummer's (1992) study of the inward and outward FDI in Korea found that inward FDI contributed to the development of the competitive advantages of their manufacturing sector. Moreover, they found evidence that inward FDI in Korea has been targeted to sectors with high capital-labor ratio, low unit wage costs and high labor productivity. This accordingly reflects the results of government efforts to limit inward FDI to certain sectors. This can also be interpreted as reflecting how these capital intensive sectors were the ones where foreign firms had competitive advantages over Korean firms.

*Taiwan*

FDI outflow from Taiwan has overtaken FDI inflow in 1986 and has consistently been more than FDI inflow (Figure 4). As the importation of technologies and technical knowhow was the strategy of the Taiwanese government, they made FDI contingent on helping Taiwanese SMEs to upgrade their operations and technologies (Thurbon and Weiss, 2006). However, with the increase in wages in the 1990s, foreign firms started to prefer subcontracting their operations to local SMEs rather than expanding their operations. As such, their affiliates exiting Taiwan were bought by Taiwanese investors. Given the increased interactions with foreign firms, Chan (2000) found evidence that FDI caused economic growth in Taiwan through technological progress.

**Figure 2. FDI flows in Taiwan as % of GDP, 1980-2010**




*Source: UNCTAD*

Before 1980s, the government was very restrictive with outward FDI as it was seen as lessening investments at home; this was reversed later on due to the sharp increase in wages and land prices which were inhibiting further investments locally, and undermining their competitiveness (Thurbon and Weiss, 2006). In particular, after the rise in prices and the rise in the value of the Taiwanese dollar in 1986, FDI outflow expanded rapidly (Chen and Chen, 1995). Moreover, China became Taiwan's largest recipient of FDI outflow. In 2013, Mainland China (60%) and the rest of Asia (20%) received 84% of the total outbound Taiwanese FDI. The preference of mainland China to investments from the Chinese diaspora was also coupled with their 2010 Economic Cooperation Framework Agreement with Taiwan, accounts for the majority of Taiwanese investment in China.

### *China*

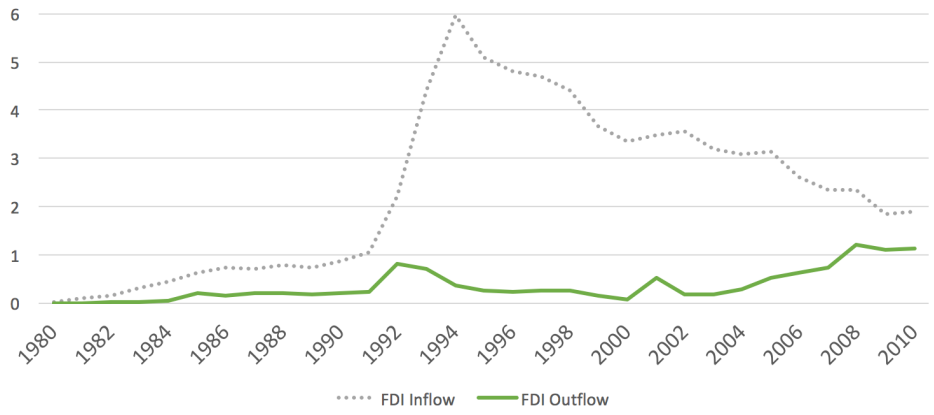
Figure 2 shows the FDI inflows and outflows in China as percentage of their respective GDP. China's FDI flows show that FDI inflow has consistently been more than FDI outflow even until 2010. The period between 1980 and 2010 reflect the Stages 1 to 3 of the IDP. From 1980 to 1990, FDI inflow remained above FDI outflow. After the Open Door Policy in 1978, China has been among the top recipient countries of FDI. The economic and cultural opening up of China was advanced to learn from the capitalist countries and to open China to

the international markets (Alvstam, et al, 2014)

At the beginning of 1990, there was an upsurge of FDI inflow. Being the industrial base of the world with its large market and cheap labor, China has also been a sourcing base for Japan, Korea, and Taiwan. Particularly in the 1980s to mid-1990s, China was seen as a sourcing base alternative to Southeast Asian countries Yang, Jiang, Kang and Ke (2009) noted that inbound FDI preceded outbound FDI, as the former was viewed by the Chinese government as a tool to prepare local firms to be more competitive. In the 1980s, Deng Xiaoping opened Special Economic Zones (SEZs) in Shenzhen, Zhuhai, Shantou, and Xiamen, where foreign trade and investments through joint ventures were allowed. These four SEZs where extended to 14 other cities in 1984. In 1986, the Chinese government offered incentives for FDI and joint ventures on export-oriented industries that use advanced technology (Baskaran and Muchie, 2008). In the 1990s, FDI inflow surged following changes in the macroeconomic policies that further supported economic liberalization. More policies to attract FDI was also put in place. As such, FDI grew from $11 billion in 1992, to $33 billion in 1994 and $45 billion in 1997. The Chinese domestic market was made open to the products by FDI, and retail trade and finance sectors were made open to foreign investment. The devaluation of Renminbi in this period also helped in expanding FDI (Lemoine, 2000). However, following the 1997 Asian Financial Crisis, the trend in FDI inflow has been declining.

After the accession of China to the World Trade Organization (WTO) in 2000, the large market of China became an attraction for market-seeking investments. In 2007, China was receiving 18.3% of total FDI sent to developing countries, or 5% of the total world FDI (Chen, Melachroinos, and Chang, 2010). With this growth in FDI inflow, Thorbecke and Salike (2013) noted that the increase in FDI in 2000 was in three areas: (1) companies with advanced technology or brand names, (2) commodities related to Chinese production, and (3) service companies useful for Chinese exports. This reflects two aspects of the Chinese government's policies towards FDI identified by Chen, et. al. (2010). The first one is the spatial restriction of FDI to special economic zones, which fostered the development of global city-regions, but worsened the income gaps between the coastal and inland regions. The second aspect is its ambiguity. While this initially hampered Western FDI, this also attracted FDI from the Chinese Diaspora, or investments from the "patriotic Chinese". This explains why in 2000, while EU, Japan and US investments were only 10% of the inflow, almost of of the inbound investments were from Hong Kong, Taiwan and Singapore (Chen, et. al., 2010).

**Figure 3. FDI flows in China as % of GDP, 1980-2010**




*Data Source: UNCTAD*

On the other hand, FDI outflow started to increase. This pattern reflects that of Stage 2 of the IDP. And lastly, in the early 2000s, growth rate of FDI outflow started to increase, and a converging trend between the two started to show. This reflects Stage 3 in the IDP.

Outflow of investments from China was part of the Open Door Policy in 1978, but the Chinese government mostly prioritized the promotion of FDI inflow. Yang, Jiang, Kang and Ke (2009) identify three stages in the growth of Chinese outbound FDI: 1978-1990, 1991-2000 and 2001-2009. The first stage commenced with the Open Door policy, where outbound FDI was included in the national economic development programs of China. Only large state trading houses were granted by the government permits to set up operations abroad. In the second stage, large state-controlled firms were allowed to directly invest

abroad. The authors noted that the main motives of the government to promote outbound investment was to allow the firms to seek sources of natural resources and to move mature industries to other developing countries. During this stage, Chinese firms also started to be listed on the stock exchanges of developed countries, and have become active in pursuing mergers and acquisitions abroad.

## 3. Inbound and Outbound R&D

One of the components of the globalization of the world economy is the globalization of R&D, where the people who invent technologies embodied in patents, and the assignees (owners) of the patents increasingly cross national borders (Guellec and van Pottelsberghe, 2001). This is evident in the cases of co-development with foreign partner, or by setting up R&D outposts abroad. Guellec and Zuniga (2006) identify two trends in the globalization of R&D: SHAI or the share of Country X's patents that have foreign inventors and local applicants (or outbound R&D); and SHIA or share of country X's patents that have local inventors and foreign applicants (or inbound R&D).

From the viewpoint of countries receiving *inbound R&D* (or being host countries of the research centers of multinational or foreign firms), particularly in the case of emerging countries, the investment on technology may bring two benefits: the direct effect of increase in production through the use of imported high-technology means of production, and the increased accessibility of

knowledge flows from advanced economies. From the viewpoint of firms pursuing *outbound R&D* (or locating research centers abroad), opening research centers in other countries provides access to foreign knowledge pool, while opening access to new markets in these countries.

## 4. Contributions and limitations of the paper

The processes of inbound R&D and outbound R&D constitute the globalization of R&D. This paper investigates the relation between globalization of R&D and national innovation system by looking at cases of countries that proactively used technology as a means of catching up in the late 20$^{th}$ century and the start of the 21$^{st}$ century. This paper traces the evolution of the R&D output of inbound and outbound FDI in the countries of Korea, Taiwan and China from 1980 to 2010 and the interaction between the inbound and outbound R&D with the development of the variables of the national innovation system.

Just as with previous studies that used patent data, this study is also limited with the shortcomings of using patent data, including the fact that firms do not always patent inventions (some prefer other strategies including secrecy), and that the value distribution of patents is skewed, i.e. the preference to patent differs across countries. As such, interpretation of the results of this study are done with caution.

More specifically, this paper aims to investigate two parts. First is the

sequencing of inbound and outbound R&D. While there are existing studies that look at the sequencing of inflow and outflow in terms of investments (Dunning and Narula, 2010; Lee and Plummer, 1992), there are no existing studies looking at the trend in R&D investments using R&D output, i.e. patents. As such, this paper will verify if an identifiable trend similarly exists for patents owned by foreign firms and invented locally, and for patents owned by local applicants and invented overseas. As Guellec and van Pottelsberghe (2001) noted, the address of the inventor indicated in the patent is usually the address of the laboratory. Using this, patents with different applicant address and inventor address were used in this study.

The second aim is to identify the relation between inbound and outbound R&D with the variables of the National Innovation System (NIS). The NIS is comprised of elements and relationships related to the production, diffusion and use of novel and economically useful knowledge or technologies (Lundvall, 1992). Lee (2013) identified three specific variables in the NIS derived from patent data that are relevant to economic growth. While Erdal and Gocer (2015) found that an increase in FDI is associated with an increase in R&D expenditures, there is a lack in the study of the dynamics associated with it's impact on the development of the NIS variables, particularly of a catching-up country. As such this paper hopes to contribute to the literature by focusing on investments specifically related to strategic assets, and how it relates to R&D output and NIS

variables of catching-up countries.

## 5. Structure of the Paper

The paper is organized as follows. Chapter II discusses the literature on the investment development path and the flows of foreign direct investments (FDI) in China, Korea and Taiwan. The literature review also looks into the globalization of R&D, and the NIS variables. The gaps in the literature are also identified in Chapter II. Chapter III outlines the theoretical framework, and the corresponding testable hypotheses are presented. Chapter IV presents the data and methodology used in this study. Chapter V presents the results and discussion. The first part shows the results of graphical trend analysis of inbound and outbound R&D in Korea, Taiwan and China. As Korea and Taiwan exhibited similar characteristics, both country cases were used for the second part of the results showing the empirical analysis of the long-run relations of globalization of R&D variables and NIS variables.

# II. LITERATURE REVIEW

In studying the dynamics of globalization of R&D and national innovation system variables, the following bodies of literature are reviewed: the investment development path, foreign direct investments in China, Korea and Taiwan, and the globalization of innovation. Gaps in the literature are identified, and from these,

## 1. Investment Development Path (IDP)

The theory on the investment development path proposes that the flow of foreign direct investment (FDI) is a function of the income level and economic structure of a country. More specifically, in the initial stage of growth, a country receives more inward flow of FDI (net inward FDI), and as the country progresses to become a developed economy, its companies start to invest in foreign markets (net outward FDI) (Dunning and Narula, 1994).

As the countries enter different stages of development, their absolute and comparative advantages change, which consequently influences the direction of the investment decisions of firms, and the investment pattern in general. The IDP builds on the eclectic paradigm which identifies three advantages (called the OLI advantages) that influence the overseas investment decision of firms: *ownership advantages* (the technology, know how, resources, and assets that a firm has or can possibly gain access to), *internalization*

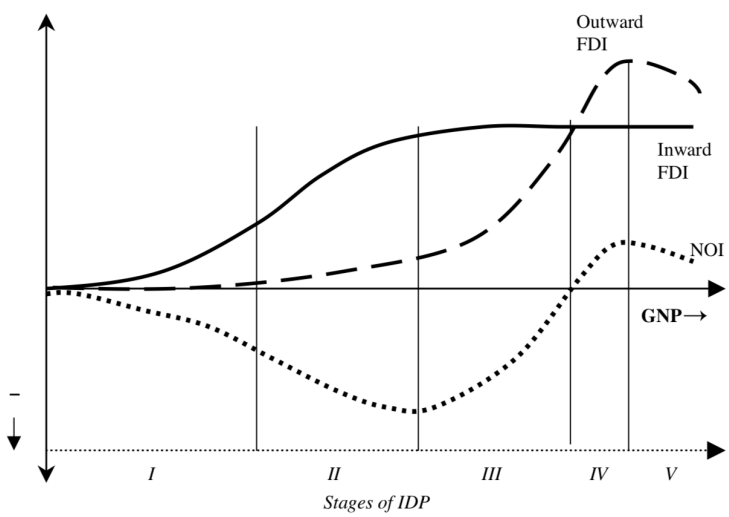
*specific advantages* (the perceived profitability of owning or controlling the value adding activities), and *locational specific advantages* (existing natural or created assets overseas that make it more profitable to pursue production activities abroad than locally) (Dunning and Narula, 1994). Given these advantages, firms decide to pursue any of these four types of investments: natural resource-seeking investment (in search for raw materials for production, including minerals), market-seeking investment (aims to supply the host market), efficiency-seeking investment (international division of labor, such as due to cheaper labor prices in host countries) and strategic asset-seeking investment (in search of assets crucial to the long-term competitiveness of the firm) (Dunning, 1994).

As regards the relationship between patterns of investment and the development stages, Dunning and Narula (1994) categorizes development into five stages (see Figure 4). Figure 4 outlines the key characteristics of each stage of development and the characteristics that define them. Specifically considering FDI flows: **Stage 1** has no FDI outflow and minimal FDI inflow, particularly in processing the natural assets of the host country; **Stage 2** has minimal increase in FDI outflow for market-seeking investments, while there is little growth in FDI inflow due to their natural assets; **Stage 3** shows gradually higher increasing growth rate for FDI outflow relative to FDI inflow, and FDI outflow will also expand to asset-seeking investments; **Stage 4** is

characterized by equal or higher FDI outflow than FDI inflow; and lastly, **Stage 5** is characterized by a trend to balance FDI flows, where investments are hierarchical with large intra-industry exchanges, and with cooperative ventures in similar products, with the management having blurred nationalities. Figure 4 shows a graphical representation of these five stages and the corresponding dynamics in the FDI flows.

Attracting foreign direct investment is one mechanism for developing countries to facilitate technology transfer. A common characteristic of economies in the developing stage is the lack of financial capital and abundance of cheap factors of production, particularly of labor. As such, in the early stages of development, the governments try to attract FDI (or FDI inflow), and the firms of these countries do not yet have the financial and technological capability to invest abroad.

**Figure 4. Graphical representation of the investment development path**




*Source: Narula and Dunning (2010). Note: not drawn in scale.*

In the case of developing or emerging countries, FDI inflow is considered as a way to improve productivity. In line with this, governments of developing countries have introduced investment incentive schemes to attract inward FDI. Firms from developed countries transfer their production plants to developing countries due to competitive sources for the factors of production. This transfer is consequently followed by the research activities of these firms. OECD reported that the transfer of productive activities to the developing world is generally followed by the similar transfer of R&D activities, as the FDI recipient countries start to offer relatively low wages with an increasing number of well-trained researchers (Chen, et al., 2010). On the other hand, firms from countries may also seek to transfer productive activities abroad in order to search for cheaper factors of production (considered as FDI outflow). Investing abroad also allows firms to adapt products to the local demand and to expand their knowledge base by acquiring lacking and complementary technological competences (Guellec and Zuniga, 2006). The following section reviews the trends on FDI in East Asia.

However, Narula and Dunning (2010) note that not all recipients of FDI inflow experience this growth, considering that there are different kinds of investments, and attracting the "right kinds" of investments, or the right kinds of activities by MNEs must be welcomed. As such, these authors proposed that in furthering the research agenda, the specific activities of MNEs should be

considered as the unit of analysis. This is particularly because while MNEs have direct benefits, their most significant contributions are indirect, depending on their type of activities, including conducting research and development. The globalization of R&D activities by MNEs is discussed in Section 2 below.

## 2. Globalization of innovation

Among the types of FDI identified in Dunning (1994) is the strategic asset-seeking investment, which is related to the long-term competitiveness of firms. This includes seeking for intangible assets such as knowledge, and building the patents owned by firms as a strategy to protect themselves from patent infringement cases by incumbent firms. Guellec and van Pottelsberghe (2001) call this the internationalization of technology, which means that "inventions, the people generating these inventions, and the ownership of these inventions" (p. 1253). This can come in different forms: scientists and engineers pursuing higher studies or their career abroad and returning to their home countries, and international alliances by firms for R&D activities. Another indicator of this phenomenon is the increase in the share of technology are owned by firms from Country X, and the inventors residing in Country Y. Guellec and van Pottelsberghe (2001) pose that this reflects how companies have research facilities in other countries.

There are two cases when multinational firms own research facilities in other countries. First is by accident, where mergers and acquisitions of firms abroad with R&D facilities are included in the transfer of firm ownership. The second case is as part of the MNE's strategy, based on three reasons. Firstly, MNEs that aim to access foreign markets would want to adapt their products to the demands of the foreign markets, and to provide technological assistance to their subsidiaries in the host country. Secondly, MNEs would "tap" foreign technologies by establishing R&D centers abroad to monitor new innovations. By being present in areas with expertise in specific technological fields, it would be easier for MNEs to access the researchers' networks and participate in research activities. The third possible reason is to access the comparative advantage of the host country which complements the MNE's core technology (Guellec and van Pottelsberghe, 2001).

Willoughby (2018) identified three waves of research regarding the relation of patent rights in the IP system and the FDI, trade and economic growth of developing countries. During the first wave in the 1990s, economists concluded that stronger IP systems in developing countries facilitated technology transfer and FDI, which in turn stimulates economic activities that promote economic growth (Maskus and Penubarti, 1995). In the second wave in the 2000s, researchers have argued that strong IP system attracted FDI, which facilitated endogenous innovation that promoted economic growth.

Lastly, in the post-2010 period, research has once again focused on the complex relationship between strong IP system and growth in developing countries.

### *Inbound R&D*

In general, the globalization of R&D can be categorized to accepting R&D activities of foreign firms (inbound), and pursuing R&D activities abroad (outbound). There is also an existing literature on international patenting, which covers firms applying for patents abroad, irrespective of the inventor's address (Willoughby, 2018; Yang and Kuo, 2004). Inbound international patenting (foreign firms applying for patents in domestic patent office) has received much academic attention, with the consensus being that patenting by non-residents in developing countries is strongly related with economic development and total factor productivity. The link between the inbound international patenting and growth was identified by Branstetter (2004) as due to the transfer of advanced technologies into the domestic market through the affiliates of the foreign firms.

### *Outbound R&D*

As regards outbound international patenting (domestic firms applying for patents abroad), Yang and Kuo (2008) noted the simultaneous growth in exports and FDI outflow with overseas patenting activities of domestic firms. This is expected as the firms would seek protection for their products in the

export markets. Other factors that influence outbound international patenting from the literature are emergence of frontier technologies (like biotechnology and nanotechnology) as researchers tend to collaborate, firm size, R&D expenditure, R&D capability, and existing high stock of cross-country patent ownership (Willoughby, 2018). In contrast, only Willoughby (2018) has investigated the effects of outbound international patenting, specifically on the economic development of countries and found strong relationship between the two variables. While Kafouros, Buckley, Sharp and Wang (2008) found that the internationalization of activities by firms improve their innovative capacity since internationalization provides access to firms on various ideas, markets and more efficient supply.

The variable of globalization of R&D used in this paper is indicated by R&D conducted by foreign companies in the country (inbound), and R&D conducted by local companies abroad (outbound). Table X shows an example of patents that could be considered as inbound and outbound R&D patents. Two patent-based indicators borrowed from Guellec and van Pottelsberghe (2001) will be used in this research for the independent variable: the share of patents made by local inventors with foreign ownership or assignees ($SHIA_i$), the share of patents made by foreign inventors owned by local assignees

($SHAI_i$).[1] Table 2 below summarizes the indicators for globalization of R&D and their respective measures. According to Guellec and van Pottelsberghe (2001), the address of the inventor indicated in the patent is mostly the address of the laboratory they work in. As such, when the inventor and assignee addresses do not match, it reflects that the patent protects a technology invented in a research facility in another country as the home country of the multinational firm.

**Table 1. Examples of inbound and outbound R&D patents**

| Application Number | Applicant | | Inventor Address | Inbound R&D | Outbound R&D |
|---|---|---|---|---|---|
| | Name | Address | | | |
| 5369045 | Texas Instruments, Incorporated | US | Seoul, Korea | X | |
| 6858521 | Samsung Electronics Co., Ltd | Korea | San Diego, US | | X |
| 7672143 | Hewlett-Packard Dev LP | US | Taipei, Taiwan | X | |
| 7806684 | United Microelectronics Corporation | Hsin-chu, Taiwan | Singapore | | X |

[1] In this study, co-ownership and co-inventorship is counted as one patent count for each assignee and inventor of the patents in favor of the fact that if firms share ownership of one patent, these firms own the entire patent.

**Table 2. Indicators of globalization of RD and their measurements**

| Indicator | Measure |
|---|---|
| SHIA or inbound R&D | $SHIA_i = \frac{PF_i^{IA}}{PFI_i}$ |
| SHAI or outbound R&D | $SHAI_i = \frac{PF_i^{AI}}{PFA_i}$ |

Where,

$PF_i^{IA}$= count of patents by local inventors of country i, owned by firms of country j i

$PFI_{ij}$ = total count of patents by inventors of country i

$PF_i^{AI}$ = count of patents by foreign inventors of countries j, owned by firms of country i

$PFA_{ij}$ = total count of patents owned by country i

The indicators used are parts of the formula for SHIA and SHAI[2], which are, in words:

Inbound R&D:

$$SHIA_i = \frac{patent\ count\ with\ foreign\ assignee,\ \ local\ inventor\ address}{total\ patent\ count\ with\ local\ inventor\ address} \qquad \text{Equation 1}$$

[2] These indicators were borrowed from Guellec and Van Pottelsberghe (2001).

As such, SHIA shows the share of the patents invented domestically that are controlled or owned by foreign firms. On the other hand, outbound R&D is the ratio of patents owned by foreign firms that are invented locally, over the total number of patents invented locally. SHAI reflects how much of patents applied for by the local firms were invented abroad.

Outbound R&D: $SHAI_i =$ Equation 2

$$\frac{patent\ count\ with\ local\ assignee,\ \ foreign\ inventor\ address}{total\ patent\ count\ with\ local\ assignee}$$

Guellec and Van Pottelsberghe (2001) also note that these variables must be considered as the lower-bounds indicators of internalization of technology, since patent data does not register the change of ownership of patents brought about, for instance, by cross-border mergers and acquisitions.

Guellec and Van Pottelsberghe (2001) found four trends in their initial analysis of these indicators derived from the database of European Patent Office (EPO) for the periods 1985-1987 and 1993-1995**. Firstly**, they found that smaller countries (geographically and economically) tend to be more internationalized. The authors proposed that this may be due to the fact that smaller countries would have fewer researchers in certain fields, which necessitate them to collaborate or go to conduct research abroad. **The second**

observation was that at these periods, inbound R&D was higher than the outbound R&D, except for some countries. This reflects the concentration of patent ownership in a few countries. **The third observation** was that the internationalization per sector or industry had less variance than across countries. Moreover, four sectors were highly internationalized: chemicals, oil refining, drugs and food and beverages. While the least internationalized were shipbuilding and aerospace. **Lastly, they found** that inbound R&D (SHIA) is negatively correlated with the number of patents invented by the residents. In other words, the lower levels of patents invented in one country, the higher the share of foreign ownership of these patents and the share of collaboration with foreign researchers. The authors propose that the small size of these countries includes a narrow range of research activities, and a higher involvement in the international division of labor.

Guellec and Van Pottelsberghe (2001) also checked the relation of these variables to the GDP and R&D intensity in their sample. They found that GDP was negatively correlated with these variables. This shows how economically smaller countries are more internationalized than the larger countries. R&D intensity was found to have a negative impact on inbound R&D, and a positive relationship with outbound R&D. This means that the more developed the research environment and capabilities are, the less they are collaborating or

depending on foreign sources of knowledge. Similarly, the higher the R&D spending of a country, they control more share of ownership of locally invented patent compared with MNEs. The authors argued that this dynamics indicate how firms from advanced or incumbent countries tend to improve their technological capabilities by foreign acquisition or foreign ownership of patents (i.e. outbound R&D).

## 3. The link between inbound and outbound R&D: National Innovation System Variables

R&D investments that form part of FDI inflow from foreign countries can influence economic growth by improving the national innovation systems of the host country. The NIS variables used in this study are adopted from Lee's (2013) book, which are the cycle time of technologies, localization of knowledge creation, and diversification of technology. The number of locally owned patents is also included to cover the quantitative effect of inbound R&D. Following from the findings of Lee's (2013) study that the other two NIS variables of originality and innovator-concentration are not relevant in explaining the success of the emerging countries, these two are not included in this study.

## *A. Cycle Time of Technologies*

Cycle time of technology can be considered as a measure of the pace of technological progress. This indicator is the median age of the patents cited by a specific patent. The literature explains that an industry with shorter cycle time of technology means faster substitution rate in the field, which in turn indicates faster technological progress (Kayal and Waters, 1999). Longer cycle times mean that older patents were cited by the patents of an application year. Lee (2013) found that Korea and Taiwan together showed a divergence from the trend of middle income countries, such that their cycle time showed a declining trend. In addition, Lee (2013) found that the cycle time of technologies is negatively correlated with economic growth. That means, that as the emerging countries progressed, the cycle time of the patents they applied for got shorter.

As earlier noted in Lee (2013), Korea and Taiwan have decreased cycle time of technologies during their catch up stage, meaning that these countries have focused on more recent technologies as a means to catch up. This is clearly seen in the graphs (Table 7), with the slowly increasing cycle time of technologies reflecting the increasing emphasis on industries with long cycle time after Korea and Taiwan have caught up. Korea and Taiwan's cycle time have gone less than 8 years around the 1980s and 1990s, respectively.

## *B. Localization of Knowledge Creation*

The localization of knowledge creation shows how much of the patents cite older patents in the same national border. One of the information contained in the patents are the citations that define the scope of the property right awarded to owner of the patent. As the patents are awarded if the technology is novel, nontrivial and useful, the patent must contain additional information over the existing state of knowledge. The previously existing knowledge is identified by the citations of the patents. That is, a patent is contributing new knowledge or information in addition to the existing knowledge contained in the previous patents that it cites.

Equation _ shows the variable of localization of knowledge creation and diffusion as the ratio of self-citation over the total number of citation made by the same country (Lee, 2013). That is, it is the share of citing previous patents within the specific country's national innovation system, which measures the level of dependence or independence on foreign sources of knowledge. Therefore, higher localization of knowledge creation reflects lesser dependence to foreign sources of knowledge. Consequently, Lee (2013) found that patents of middle-income countries showed to have a lower degree of localization of knowledge creation. Moreover, the average for Korea and Taiwan's localization of knowledge creation started below that of the average of middle

income countries and caught up in the mid-1990s. In 2000, the average of Korea and Taiwan equaled the level of the high-income countries.

$$\text{Localization of knowledge creation} = \frac{\text{number of citations made to country x's patents by country x's patents filed in year t}}{\text{number of all citations made by country x's patents filed in year t}}$$

## *C. Diversification*

The final NIS variable considered in this study is diversification—i.e. the number of technological fields where these countries applied for in a given year. Technological diversification measures the wider range of technological classes of the patents applied by a country. Lee (2013) argues that higher diversification reflects higher technological capabilities of the NIS, and favors further technological innovation. Furthermore, he found out that technological diversification in shorter cycle time technologies were present in Korea and Taiwan. Kim, Lim and Park (2009) also found evidence that technological diversification by firms investing in technologies related to their core technology was significant and positively related to firm performance.

Higher degree of diversification reflects patenting in various technological fields, while lower levels of diversification shows focus on

specific fields of technology. In the case of Korea and Taiwan, despite the decreasing rate of inbound R&D, they managed to have high degree of diversification, exhibiting their R&D capabilities. Lee (2013) noted that high degree of diversification also favors further technological innovation, stemming from growth in the learning in different kinds or fields of technology.

## 4. Research Gap

Existing studies on FDI look at the flow of investments, both inward and outward, and relating them to macroeconomic indicators of certain countries, such as FDI's impact on the the competitive advantages of a country (Lee and Plummer, 1992), and the trends in the flow of R&D investments (Alvstam, Dolles, and Ström, 2014; Thurbon and Weiss, 2006). However, existing literature does not focus on the pattern of flows in terms of investment specifically for R&D activities by firms. The literature (Dunning and Narula, 1994; Lee and Plummer, 1992), focuses on FDI in general, without separating investments specifically for research and development. This is despite the fact that FDI is considered as one of the channels to transfer knowledge across borders, including from developed countries to developing countries. This would generate interesting policy implications, particularly for the latter. As such, this paper would contribute to this literature by investigating the output of R&D investments part of FDI

On the other hand, existing studies on international patenting investigate its relation with economic development in the home country of the inventors (Willoughby, 2018), the influence of the presence of cross-border knowledge networks such as global R&D centers by MNEs on commercialization in frontier technology (i.e. nanotechnology) (Shapira, et al., 2011), the drivers that cause cross-boarder ownership of patents (Dachs & Pyka, 2010), and the trends in international patenting (Guellec and van Pottelsberghe, 2001). The existing literature using patent data to study globalization of innovation looks at the relationship between globalization of R&D and GDP and R&D intensity (Guellec and van Pottelsberghe, 2001), knowledge flows through patent citations (Hu and Jaffe, 2001). Even the work by Willoughby (2018) looks at patenting done by domestic firms in foreign patent offices, regardless of where the technologies described by the patents were invented. While there is also an existing literature looking separately at the trends in the NIS variables and its relation with economic growth (Lee, 2013). This thesis aims to address the gap between these two bodies of literature (on globalization of R&D variables and NIS variables), to investigate what are the possible effects of the opening up of countries to FDI inflows and FDI outflows which also include investments related to R&D activities.

# III. Theoretical Framework and Hypotheses

Given the gaps in the literature and following the logic of IDP, the main hypothesis of this paper is that *at the early stages of development, inbound R&D comes first and helps to build the national innovation system variables, and outbound R&D comes later at the advanced stages of development.* The paper investigates this in two parts. The first part examines the dynamics or sequencing between the two variables of the globalization of R&D (inbound and outbound R&D).

As such the following research question is posed: *Do the trends in FDI flows reflect the trends between inbound and outbound R&D in China, Korea and Taiwan?* Specifically, *does inbound R&D precede outbound R&D in Korea and Taiwan?*

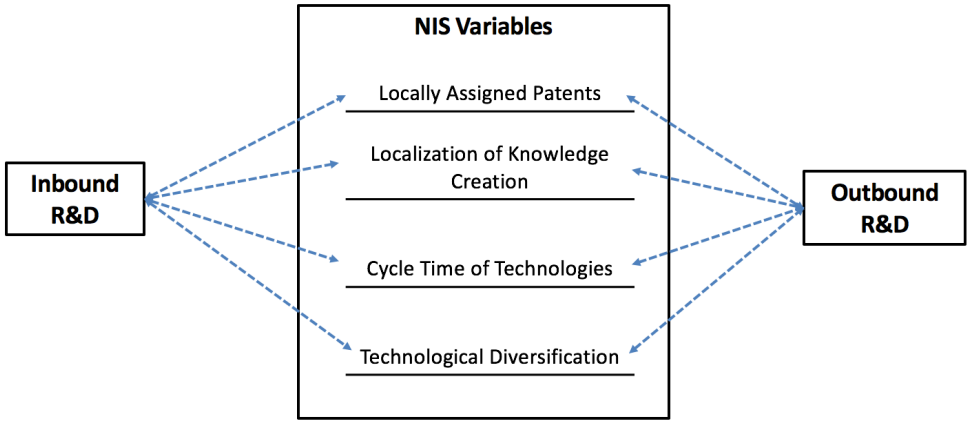
The second part investigates the relations specifically between the globalization variables (inbound R&D and outbound R&D) and the NIS variables. Borrowing the conceptualization from the investment development path, this paper hypothesizes, in summary, that as inbound R&D came first, inbound R&D helped improve the NIS variables, and that as the firms inside the NIS gained technological and financial capabilities, they were able to pursue R&D activities abroad, i.e. outbound R&D.

More specifically, the research questions of this study are as follows:

1. Do the trends between inbound and outbound R&D reflect the FDI flows in China, Korea and Taiwan?
2. How does inbound R&D relate with the NIS variables in Korea and Taiwan?
3. How does outbound R&D relate with the NIS variables in Korea and Taiwan?

From these research questions, the following theoretical framework was conceptualized. The next section discusses the testable hypotheses derived from this framework.

**Figure 5. Theoretical Framework**




## 1. Inbound R&D and NIS variables

From this framework, 16 testable hypotheses were derived. Some studies found that the inflow of FDI, depending on the type of activities that

the firms conduct in the host country, improves the productivity of the host market. In the same vein, R&D activities that foreign firms conduct in the host market could also be expected to influence the domestic national innovation system of the host country. Specifically, the R&D activities that foreign firms conduct in the host country can be expected to bring in new ideas and technology in the domestic system which can stir other firms to engage in patenting activities as well. In addition, the movement of R&D personnel between the foreign and local firms can also influence the domestic firms to include patenting as part of their corporate strategy. Moreover, this paper also tested for bidirectional relationships. When local firms start to own more patents, foreign multinational companies can identify the catching up country as a potential technological hub and establish R&D outposts. As a result, inbound R&D may be expected to increase. As such, the following hypotheses are put to test.

*H1: Previous values of inbound R&D help predict current values of locally assigned patents in the long-run.*

*H2: Previous values of locally assigned patents help predict current values of inbound R&D in the long-run.*

In addition, inbound R&D can also be expected to influence not only the quantitative aspect of the domestic innovation system. One of the objectives

of governments to welcome FDI is to bring in foreign technology. Lee (2013) found that Korea and Taiwan together showed a divergence from the trend of middle income countries, such that their cycle time showed a declining trend in 1980s and 1990s. In addition, Lee (2013) found out that the cycle time of technologies is negatively correlated with economic growth. That means, that as the emerging countries progressed, the cycle time of the patents they applied for got shorter. On the other hand, an increase in the cycle time reflects the entrance into long-cycle time technologies with older patents that are mostly owned by incumbent or developed countries. As inbound R&D from firms can contribute to bringing in more advanced technology, it can be expected to influence the cycle time of technologies of the patents of local firms. It can be expected that inbound R&D can contribute to the host country's national innovation system by bringing in the latest technology and influencing the local firms, particularly in their R&D decisions. Possible channels for this influence are through competition, through working with the local firms by subcontracting operations, or through allowing access to intermediate goods. Along with checking for bidirectional relationship, the following hypotheses are tested.

*H3: Previous values of inbound R&D help predict current values of the length of cycle time of technologies in the long-run.*

*H4: Previous values of cycle time of technologies help predict current values of inbound R&D in the long-run.*

One of the factors mentioned by Lee (2013) that could affect the speed of the localization of knowledge creation is the ownership of the firm. In this respect, Lee (2013) argued that knowledge creation by foreign firms, entering the local economy through FDIs or subsidiaries of MNCs, relies more on the existing knowledge base in the home country or in the global network. With this, it can be expected that a declining trend in inbound R&D, coupled with increasing productivity of locally assigned patents would decrease the dependence on foreign sources of knowledge, i.e. increase the localization of knowledge creation and diffusion. Lesser dependence on inbound R&D would indicate stronger R&D capabilities of local firms. As such, firms are expected to depend more on local sources of knowledge to cite in their patents. On the other hand, as new patents increasingly depend on (or cite) locally owned patents (increased localization variable), there will be a decline in the dependence on foreign sources of knowledge (e.g. inbound R&D). Given this, the following hypotheses are tested.

*H5: Previous values of inbound R&D help predict current values of localization of knowledge creation in the long-run.*

*H6: Previous values of localization of knowledge creation help predict current values of inbound R&D in the long-run.*

Technological diversification measures the wider range of technological classes of the patents applied by a country. Lee (2013) argues that higher diversification reflects higher technological capabilities of the NIS, and favors further technological innovation. Furthermore, he found out that technological diversification in shorter cycle time technologies were present in Korea and Taiwan. However, he noted that it is not clear which 'caused' which.

The diversification of technological patents applied by the firms of a country reflects their technological capabilities. High diversification means high technological capabilities. Similarly, low dependence on foreign firms to conduct domestic R&D, or low inbound R&D, means high technological capability. Lesser dependence on inbound R&D would indicate stronger R&D capabilities of local firms. As such, lower share of inbound R&D would be simultaneous to entrance into various technology sectors by local firms. On the other hand, increased diversification reflects stronger NIS, as "Technological diversification, or spreading technological resources over a wider range of technological classes, represents higher technological capability, and it

functions in favor of further technological innovation" (Lee, 2013, p. 89). As such, declining dependence on inbound R&D can be expected. These are tested in the following hypotheses.

*H7: Previous values of inbound R&D help predict current values of diversification of patent classes in the long-run.*

*H8: Previous values of diversification help predict current values of inbound R&D in the long run.*

## 2. Outbound R&D and NIS variables

Following the logic of IDP, the improvement in the NIS of the host country is expected to make firms from the host country capable of pursuing R&D activities abroad, as the local firms start to look for export markets. As such, the four NIS variables are also considered as variables that could explain the trend of outbound R&D. This paper also tests for bidirectional long-run relationships between the NIS variables and outbound R&D

Hypotheses 9, 11, 13 and 15 are rooted on the reasoning that growth in capabilities of the firms facilitate local firms' activities abroad. The growth in capabilities is reflected in the NIS variables. On the other hand, as the local

firms establish more R&D outposts abroad to monitor developments in frontier technologies, it can be expected that this will influence the patenting activities of the local firms. Specifically, we can expect growth in the locally assigned patents of the local firms. As such, the follow hypotheses are considered.

*H9: Previous values of locally assigned patents help predict current values of outbound R&D in the long-run.*

*H10: Previous values of outbound R&D help predict current values of locally assigned patents in the long-run.*

Lee (2013) presents that entrance into sectors with shorter-cycle time technologies is a strategic move that supports growth. As a result, if local firms strategize to target short-cycle technology, these firms would grow and would be able to build the R&D and financial capabilities to conduct R&D activities abroad. On the other hand, exposure to export markets and access to other technological centers can be expected to influence the sectors in which local firms will specialize in. As a result, the firms can be exposed to shorter cycle time of technologies. This is tested in the following hypotheses.

*H11: Previous values of cycle time of technologies help predict current values of outbound R&D in the long-run.*

*H12: Previous values of outbound R&D help predict current values of cycle time of technologies in the long run.*

Similarly, as the countries start to increase their stock of locally owned patents, they could cite their own patents, i.e. increase in the localization of knowledge creation. As a result, this can predict the outbound R&D trends of the local firms. While outbound R&D can build the patent stock of firms that will in turn increase the chances for new patents to cite locally owned patents (i.e. increasing localization of knowledge creation). As such, the following hypotheses are tested.

*H13: Previous values of localization of knowledge creation help predict current values of outbound R&D in the long-run.*

*H14: Previous values of outbound R&D help predict current values of localization of knowledge creation in the long-run.*

When innovative firms diversify their patent classes, this can indicate that the firms are entering into new sectors with higher value added, or into

new segments within the same industry. This reflects more R&D capabilities for firms, and can thus be expected to increase the probability of firms conducting R&D activities abroad. On the other hand, overseas R&D outposts provides access for local firms to foreign sources of knowledge that can diversify their sectors or patent classes. As such, the following hypotheses are tested.

*H15: Previous values of diversification of patent classes help predict current values of outbound R&D in the long-run.*

*H16: Previous values of outbound R&D help predict current values of diversification of patent classes in the long-run.*

## 3. Relationships among the NIS variables

In order to further understand the dynamics between the period of receiving high amounts of inbound R&D and sending out outbound R&D, this paper also tested for long-run relationships among NIS variables. In general, improving one of the variables in the NIS can be expected to improve other variables in the NIS.

As such, an increasing trend of locally assigned patents is expected to help predict values of cycle time of technologies, localization of knowledge creation, and diversification.

*H17: Previous values of locally assigned patents help predict current values of cycle time of technologies in the long-run.*

*H18: Previous values of locally assigned patents help predict current values of localization of knowledge creation in the long-run.*

*H19: Previous values of locally assigned patents help predict current values of diversification in the long-run.*

Since technologies with shorter cycle-times embody the latest technologies, these new technologies use new patents, and not the older patents that are owned by advanced countries. As such, shorter cycle time of technologies in a national patent system is expected to bring the following results:

*H20: Previous values of cycle time of technologies help predict current values of locally assigned patents in the long run.*

*H21: Previous values of cycle time of technologies help predict current values of localization of knowledge creation in the long run.*

*H22: Previous values of cycle time of technologies help predict current values of diversification in the long run.*

Higher localization of knowledge creation with higher citations made to existing patents within the national border represents a stronger NIS. As such, the localization variable is expected to bring the following results:

*H23: Previous values of localization of knowledge creation help predict current values of locally assigned patents in the long run.*

*H24: Previous values of localization of knowledge creation help predict current values of cycle time of technologies in the long run.*

*H25: Previous values of localization of knowledge creation help predict current values of diversification in the long run.*

The variable of technological diversification "represents higher technological capability, and it functions in favor of further technological innovation" (Lee, 2013, p. 89). As such, higher diversification is expected to build stronger NIS variables, and this is confirmed through the following hypotheses.

*H26: Previous values of diversification help predict current values of locally assigned patents in the long run.*

*H27: Previous values of diversification help predict current values of cycle time of technologies in the long run.*

*H28: Previous values of diversification help predict current values of localization of knowledge creation in the long run.*

# IV. Data and Methodology

## 1. Data

This paper uses patent data (1) to assess the patterns or trends for inbound and outbound R&D in Korea, Taiwan and China, and (2) to check for the long-run relationships among the inbound R&D, outbound R&D and NIS variables in Korea and Taiwan.

For the globalization of R&D variables, a measure proposed by Guellec and van Pottelsberghe (2001) presented in Chapter II is used. Specifically, the inventor address and assignee address were gathered from the Connecting Outcome Measures in Entrepreneurship Technology and Science (COMETS) Database hosted by the Kauffman Foundation at www.kauffman.org/microsites/comets. From the patent database, the following information were retrieved: patent ID of the patents owned by firms from country *i* ("patent_id" based on "country_code" in the "patent_assignees" file), patent ID of patents invented by inventors from country *i* ("patent_id" based on "country_code" in the "patent_inventors" file).[1]

**Table 3. Data sources**

| Data | Source |
|---|---|
| Inbound R&D | COMETS Database |
| Outbound R&D | COMETS Database |
| Locally Assigned Patents | COMETS Database |

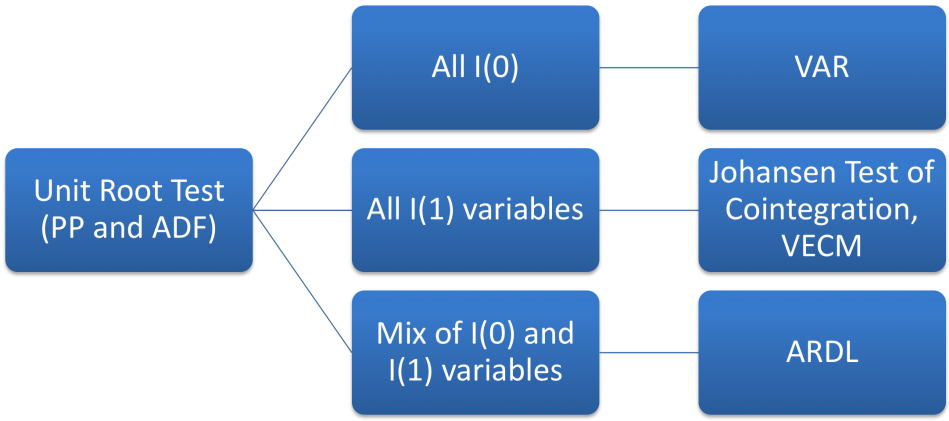
[1] A detailed enumeration of how the globalization variables were constructed is in Appendix A.

| | |
|---|---|
| Cycle Time of Technologies | USPTO* |
| Localization of Knowledge Creation | USPTO* |
| Diversification | USPTO* |

*The variables used were from USPTO Patent Database processed by Jongho Lee (forthcoming).

As this paper has two parts, the first part is addressed using graphical trend analysis. The second part examines the relationship of the previous values of the variables with the current variables using bivariate Vector Error Correction Model (VECM), Vector Autoregression (VAR) or Autoregressive-Distributed Lag (ARDL), based on the stationarity of the variables. These three models all test how the previous values of variables in the system are able to predict the current value of a variable.

**Figure 6. Appropriate tests based on stationarity of variables**



## 2.a. Unit Root Tests

The first step is to check for the existence of unit root in the variables. In this paper, Phillips-Perron (PP) (1988) test and the Augmented Dickey-Fuller (ADF) test were used. Both tests have the null hypothesis of existence of unit root. Specifically, ADF tests the null that the series is I(1), with the alternative that it is I(0). The test regression on which the ADF test is based on the least squares estimates of

$$y_t = \beta' \boldsymbol{D}_t + \emptyset y_{t-1} + \sum_{j=1}^{p} \psi_j \Delta y_{t-j} + \varepsilon_t \ ,$$

where $\boldsymbol{D}_t$ is a vector of deterministic terms such as constants, and there are p lags considered. The error term $\varepsilon_t$ is assumed to be homoscedastic. The ADF t-statistic is based on the least squares estimates of the test regression, and is tested in the following:

$$ADF_t = t_{\emptyset=1} = \frac{\widehat{\emptyset} - 1}{SE\ (\emptyset)}$$

As such, the hypotheses of interest are,

H0: $\emptyset = 1 \rightarrow y_t \sim$ I(1)

H1: $|\emptyset| < 1 \rightarrow y_t \sim$ I(0)

The difference between PP unit root tests and ADF is that the former ignores serial correlation in the test regression. The test regression for PP is

$$\Delta y_t = \beta' \boldsymbol{D}_t + \pi y_{t-1} + \mu_t$$

and $\mu_t$ is considered I(0) and may be heteroskedastic. This is the advantage of PP tests as they "are robust to general forms of heteroskedasticity…(and) the user does not have to specify a lag length for the test regression" (Zivot and Wang, 2007).

## 2.b. VAR

Figure 14 shows the flow of the processes after the unit root test. Based on the stationarity of the variables, the appropriate tests for the bivariate equations were chosen. For tests with both variables stationary at level (i.e. they are I(0) processes), Equation 3 (VAR) was used, and Wald Test statistic was conducted to check the significance of the lagged values of x with the current values of y. A bivariate VAR system has two variables, with each variable having a linear function with the number of lags of itself and the other variable.

$$\begin{bmatrix} y_{1,it} \\ y_{2,it} \end{bmatrix} = \begin{bmatrix} \alpha_{1,i} \\ \alpha_{2,i} \end{bmatrix} + \begin{bmatrix} \beta_{11}\beta_{12} \\ \beta_{21}\beta_{22} \end{bmatrix} \begin{bmatrix} z_{1,it} \\ z_{2,it} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,it} \\ \varepsilon_{2,it} \end{bmatrix} \qquad \text{Equation 3}$$

Matrix of variables: $\begin{bmatrix} y_{1,it} \\ y_{2,it} \end{bmatrix}$

Matrix of coefficients: $\begin{bmatrix} \beta_{11}\beta_{12} \\ \beta_{21}\beta_{22} \end{bmatrix}$

Matrix of lagged values of y variables : $\begin{bmatrix} z_{1,it} \\ z_{2,it} \end{bmatrix}$

Disturbance (white noise) term: $\varepsilon_{1,it}$

After the VAR, the Granger causality test command in stata is run. The null hypothesis of this test is $x \not\Rightarrow y$ and is represented as H0: $\beta_{11} = \beta_{11} = 0$ . This is tested using a standard Wald $F$ or $\chi^2$ test.

## 2.c. VECM

For tests with both variables not stationary at level and stationary at first difference (i.e. they are I(1) processes), Johansen test of Cointegration was used to identify if the combination of this collection is co-integrated. After the test of cointegration, Equation 4 (VECM) was used, where the negative and significant error correction term reflects a long run relationship between the two variables.

$$\Delta Y_t = \beta_0 + \sum_{i=1}^{n} \beta_i \, \Delta y_{t-i} + \sum_{i=0}^{n} \delta_i \Delta x_{t-i} \; + \; \varphi z_{t-1} + \mu_t \qquad \text{Equation 4}$$

Short-run coefficients: $\beta_i$ , $\delta_i$

Error Correction Term: $\varphi$

Disturbance (white noise) term: $\mu_t$

The null hypothesis H0: $\varphi = 0$. In this paper, the ECT $\varphi$ must be significant and in the range [-1, 0] to confirm long-run error correction.

## 2.d. ARDL

Lastly, for the variables with mixed stationary at level and stationary at first difference (i.e. they are mixed with I(0) and I(1) processes), Pesaran and Shin's (1995) ARDL model was used (Equation 5).

$$\Delta Y_t = \beta_0 + \sum_{i=1}^{n} \beta_i \, \Delta y_{t-i} + \sum_{i=0}^{n} \delta_i \Delta x_{t-i} + \varphi_1 y_{t-1} + \varphi_2 x_{t-1} + \mu_t \qquad \text{Equation 5}$$

Short-run coefficients: $\beta_i$ , $\delta_i$

ARDL long-run coefficients: $\varphi_1$, $\varphi_2$

Disturbance (white noise) term: $\mu_t$

Similar with the VECM, the long-run coefficients must have a value ranging between [-1, 0] and must be significant to indicate long-run relationship.

# V. Results and Discussion

The first part in this chapter looks at the facts from the trends in inbound R&D and outbound R&D in China, Korea and Taiwan. Given the hypothesis from the investment development path, empirically testable hypotheses were drawn relating the inbound R&D of these three countries and their respective NIS variables. This is presented in the second part of this chapter.

## 1. Graphical Trend Analysis of inbound and outbound R&D

Table 3 shows the summary statistics of variables related to globalization of R&D: inbound R&D patent count, locally invented patents, SHIA, outbound R&D patent count, locally owned patents and SHAI. The data is from the COMETS patent database, which contained patent applications from USPTO. The same database also included the addresses of the inventors and of the assignees (the owners of the patents).

The table shows that Korea has the highest maximum value in the locally invented patents and locally owned patents, followed by Taiwan in both variables. In comparing their inbound patent counts, China (948) has the most number of patents (maximum value) owned by foreigners and invented locally, while Korea (174) has the least. Reversely, Korea (859) has the largest maximum in the outbound patent count, followed by Taiwan (777) and China

(70). The succeeding sections looks at facts derived from the patterns in the inbound and outbound R&D patents of these three countries.

**Table 4. Summary statistics of globalization of R&D variables**

| | Variable Name | Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|---|
| Korea | Inbound patent count | i_patct | 30 | 66.27 | 64.32 | 1 | 174 |
| | Locally invented patents | i_loc_inv | 31 | 2138.77 | 2343.07 | 2 | 7026 |
| | SHIA | i_shia | 31 | 0.08 | 0.11 | 0 | 0.5 |
| | Outbound patent count | o_patct | 26 | 253.27 | 269.11 | 1 | 859 |
| | Locally owned patents | lass | 31 | 2127.94 | 2345.17 | 1 | 7028 |
| | SHAI | o_shai | 31 | 0.07 | 0.05 | 0 | 0.222 |
| Taiwan | Inbound patent count | i_patct | 31 | 92.81 | 87.31 | 2 | 277 |
| | Locally invented patents | i_loc_inv | 31 | 1542.58 | 1792.01 | 8 | 4803 |
| | SHIA | i_shia | 31 | 0.20 | 0.20 | 0.03 | 0.8 |
| | Outbound patent count | o_patct | 29 | 192.21 | 247.62 | 1 | 777 |
| | Locally owned patents | lass | 31 | 1580.23 | 1876.16 | 3 | 5063 |
| | SHAI | o_shai | 31 | 0.10 | 0.08 | 0 | 0.33 |

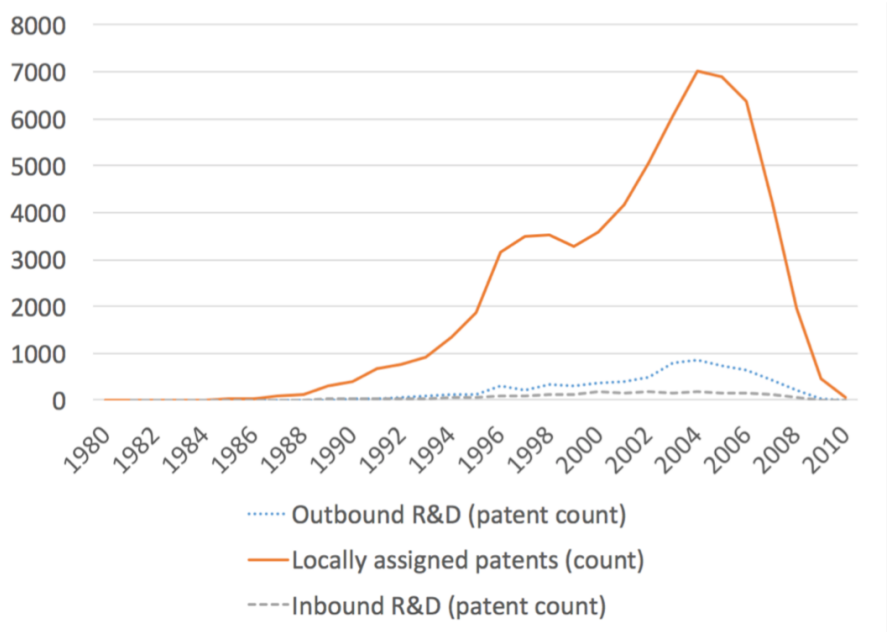
In examining the trends in Korea and Taiwan, three observations were gathered. The succeeding sections present these observations.

## 1.a. Observation 1: Locally assigned patents higher since 1980s

From Figure 7, it is evident that locally assigned patents have been more than inbound and outbound R&D patent counts since the 1980s in Korea. Figure 8 below shows a more detailed graph of the trend from 1980 to 1990 in the case of Korea. Even in the 1980s, Korean firms have owned more patents

than the patents owned by foreign firms that were invented inside Korea. This is expected since Korea began its catch up process in the period between mid-1970s to mid-1980s (Lee & Kim, 2010).

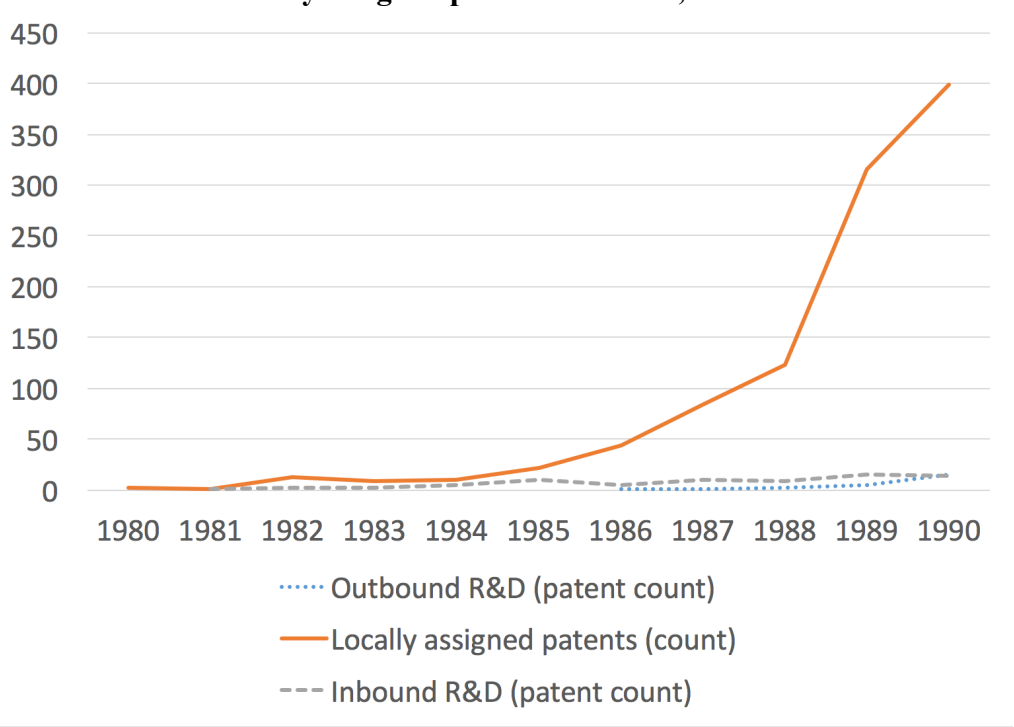
**Figure 7. Patent counts of inbound R&D, outbound R&D and locally assigned patents in Korea, 1980-2010**




By mid-1980s, Korean firms had already begun to establish in-house R&D. From mid-1980s to mid-1990s, building the firm's local technological capabilities became the evident next step as licensing and importing foreign technologies proved to be limited. The government further encouraged firms to open in-house R&D by introducing a system to register private research institutes in 1981, with benefits such as tax waivers, military service exemption and tariff exemption when importing equipment for research (Lee and Kim,

2010). The low level of inbound R&D also reflects the fact that Korea did not rely on FDI as their source of foreign technologies. Licensing, importation of capital goods, reverse engineering, and original equipment manufacture (OEM) contracts – and not FDI—were the mechanisms used by Korean firms to access foreign technology (Kim, 2003).

**Figure 8. Patent counts of inbound R&D, outbound R&D and locally assigned patents in Korea, 1980-1990**




Another reason for Korean firms to start filing patents abroad is to avoid the costly IPR conflicts with the firms from more advanced countries. Some of the IPR conflicts in the 1980s included cases on DRAM (Samsung Electronics

vs. Texas Instruments). As Korean firms expanded in the global market, they faced the challenge of patent conflicts, and as such, Lee and Kim (2010) also observed an increase in the patenting trend of Korean firms in the USPTO, increasing from 19 patents in 1985, to more than a thousand in 1995. This pattern of higher patents by Korean firms was also reflected in the Korean IPR system where foreign firms dominated the number of patent applications in the earlier stage, and where the local firms eventually applied for more patents than by foreign firms (Lee and Kim, 2010). This result, therefore, reflects that the Korean firms have gained technological capabilities by the 1980s.

Lee and Kim (2010) also argue that with the introduction of substance patents in the Korean IPR system in 1986, pharmaceuticals and other related industries realized the importance of R&D and brought about the spike in the patent applications of Korean firms in the local patent office, particularly in the 1990s. This is also reflected in the patents abroad, with the same trend observed in Figure 6.

In addition to improving their local R&D capabilities, another factor that contributed to the spike in the locally assigned patents is the merger and acquisition (M&A) strategy of Korean firms to gain ownership of foreign technologies. One case documented by Lee and Kim (2010) is the acquisition of an American company, Zenith, by LG. LG started with owning 15% of the share in 1990, to 50% in 1996, and to 100% in 2000. With this, LG was able to

gain ownership of the core technology for digital signaling, at the time when North America was transitioning to digital TV. Locally, with the restrictions in FDI and early dependence on importation of capital goods and foreign licensing, Korean firms were able to stir their technological learning by reverse-engineering foreign technologies (Kim, 2003). This could contribute to the higher locally owned patents even in the 1980s.

In the case of Taiwan, locally assigned patents has also been consistently above inbound R&D and outbound R&D patent count since the 1980s (Figure 9). Locally assigned patents and patents owned by foreign firms invented inside Taiwan (inbound R&D) were about the same level until the mid-1980s, when locally assigned patents started to increase more rapidly (Figure 10). By 1996, the locally assigned patents grew by 72%, and Taiwan firms have started to apply for more than a thousand patents every year.

**Figure 9. Patent counts of inbound R&D, outbound R&D and locally assigned patents in Taiwan, 1980-2010**

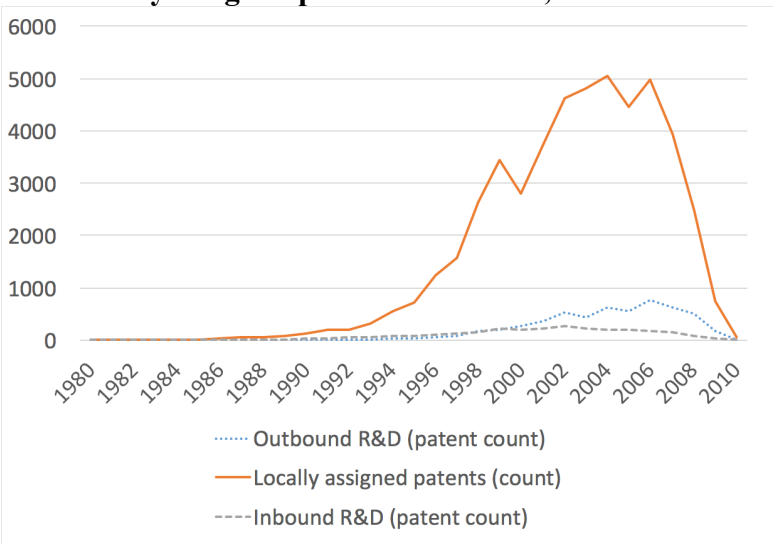
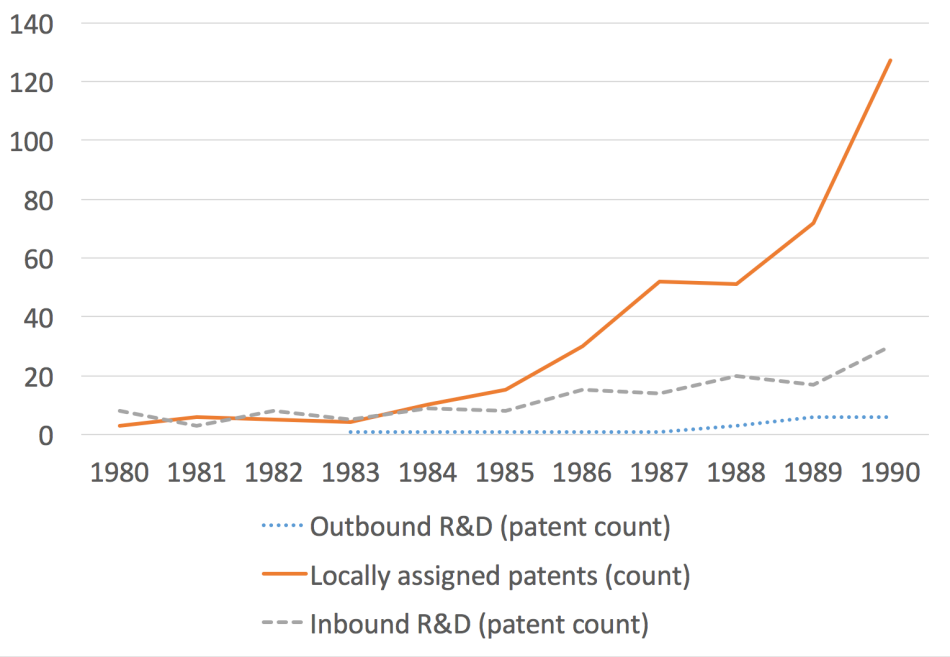


**Figure 10. Patent counts of inbound R&D, outbound R&D and locally assigned patents in Taiwan, 1980-1990**




Since Taiwan has been moving away from labor-intensive agricultural industries into technology-intensive industries since the 1980s, the period before 1995, was characterized by the beginning of export oriented industries, albeit the government was unable to successfully introduce the concept of intellectual property protection in the society. For instance, Taiwan was listed as a Priority Foreign Country of the Special 301 Report of the US Government in 1992 and 1993. However, firms engaged in exporting activities have acknowledged the importance of patent protection, due to (1) increasing patent infringement lawsuits by foreign competition (e.g. Acer versus Apple in 1982;

UMC versus National Semiconductor Corporation in 1985; and Acer versus IBM in 1989), and (2) profit from royalty payments (Wu, et al., 2010). However, as international patent disputes even through the 1990s had only been increasing, Taiwanese firms devoted more resources for IPR management and application of patents particularly in its major export market, the United States.

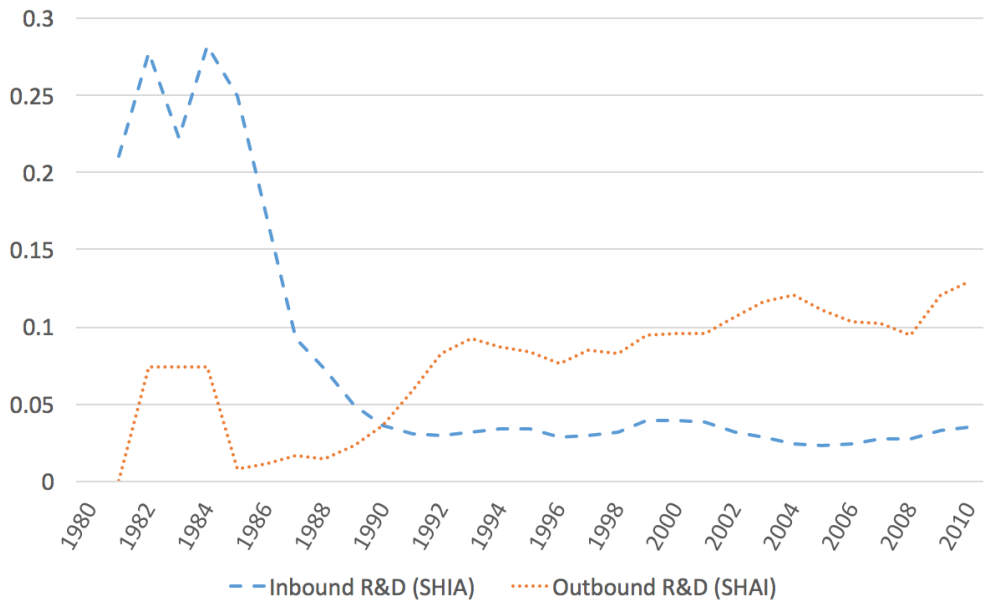
Taiwan joined WTO in 2002, after negotiations to make their IPR regime fully compliant which is required of WTO entry. The internationally harmonized and strictly enforced IPR regime helped Taiwanese firms to work with foreign firms through technology alliances and transfers. Moreover, they were able to conduct technology or IPR trading. This allowed Taiwanese firms to further access foreign technology, and became an incentive to apply for more patents (Wu, et al., 2010).

## 1.b. Observation 2: More inbound R&D until 1990 (Korea) and 1998 (Taiwan)

Figures 11 and 9 show that for both Korea and Taiwan inbound R&D occurred first in the early 1980s. Given the trends in their inflow and outflow of FDI and the investment development theory, inbound R&D is expected to be high in the developing (catching-up) stage of these three countries. This can be expected for two reasons. First, is that as foreign multinational companies from developed countries expand their market in developing countries, they

start to conduct research and product development near their production sites mainly to adapt their product to the local market.

**Figure 11. Inbound and Outbound R&D shares in Korea, 1980-2010**




In line with the growth of R&D centers locally, overseas branches were also established and by 1994, there were already 51 R&D centers abroad (Lee and Kim, 2010). This trend in the 1980s reflects Stages 1 and 2 in the investment development theory (IDP) where FDI inflow comes first, and then FDI outflow follows at a later stage. Figure 2 of the FDI flows in Korea as % of GDP shows that the period between 1980 and 1990 showed almost a balanced trajectory between FDI inflow and FDI outflow, suggesting the resource-seeking and market-seeking investments by Korean firms. However,

the early 1980s still belong to the beginning of the catch-up period of Korea (Lee & Kim, 2010). From the mid-1970s to mid-1980s, Korean firms actively imported foreign technologies, in order to pursue imitative innovation. The government helped the *chaebols* to achieve this by relaxing the rules on the importation of technologies. In 1984, the government allowed for the automatic approval of technology imports (Lee and Kim, 2010). Since inbound R&D patents are patents owned by foreign firms invented in Korea, this suggests that Korea was then able to conduct R&D locally, but was still not as frequently engaged in R&D activities abroad.

In this same period, the mechanisms for technology transfer used by Korean firms' technology were through importation of capital goods and the licensing or technology imports. Around this time period, there was also a higher share of foreign owned patents in the Korean patent regime, indicating high interest of foreign inventors to protect their technology inside Korea (Lee & Kim, 2010). Logically, advanced countries would also extend the protection of their technologies developed or designed inside Korea abroad, for instance, by applying for patents in the USPTO.

In addition, the harmonization of Korean IP laws with other advanced countries such as Japan (patent treaty with Japan in 1974) and the US (patent treaty with the US in 1978) and the eventual accession of Korea to the Patent Cooperation Treaty in 1984 also facilitated the ease of applying for patents for

technologies developed in Korea to patent offices abroad (Lee & Kim, 2010). In sum, this high share of foreign patents in the Korean IPR and the initially higher inbound R&D patent counts compared with outbound R&D patent counts shows that foreign firms in the early 1980s had more resources and technologies to apply for protection, and that there was and rising interest of foreign inventors in Korea.

In Taiwan, considering the trends of outbound and inbound R&D (Figures 12 and 13), it is evident that foreign firms with intellectual property in Taiwan to protect (inbound R&D) were applying for more patents than the patents of Taiwanese firms resulting from R&D activities abroad (outbound R&D). From 1980 to 1990, these two measures have also been growing at a steady rate, with inbound R&D averaging around 10.7 patents a year, and outbound R&D averaging 2.5 patents per year. The characteristics of high growth of inflow and steady increase of outflow are reflective of Stages 1 and 2 in the investment development path.

While inbound R&D persistently exceeded that of outbound R&D until the late 1990s, Figure 4 shows that FDI outflow has already exceeded FDI inflow since 1986. This suggests that while Taiwan was engaged in overseas investments, the nature of these investments were likely to exploit cheaper production costs (such as resource-seeking investments), and not to look for foreign technology (that is, not strategic assets-seeking investments).

**Figure 12. Inbound and Outbound R&D shares in Taiwan, 1980-2010**

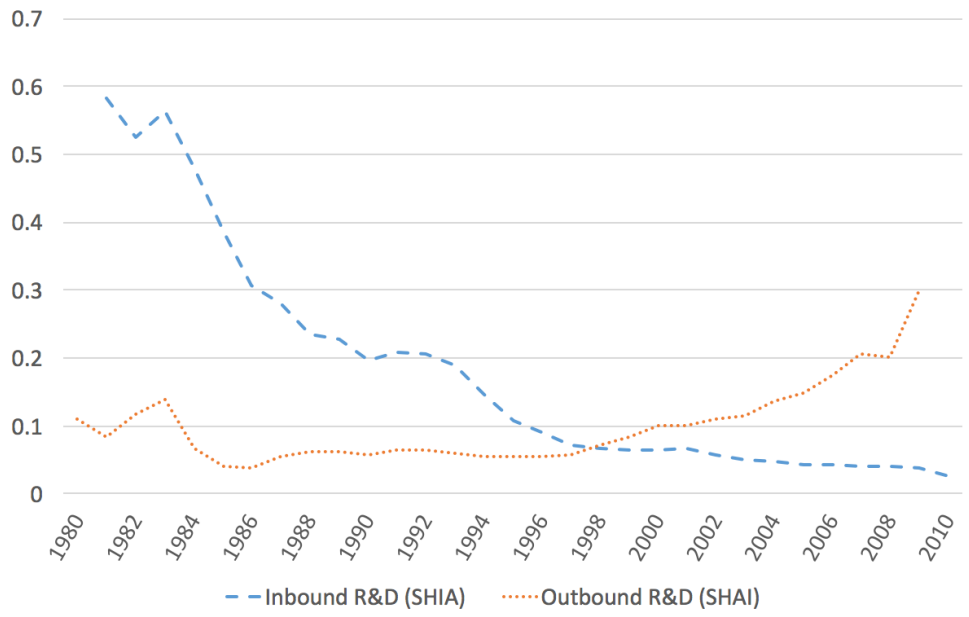
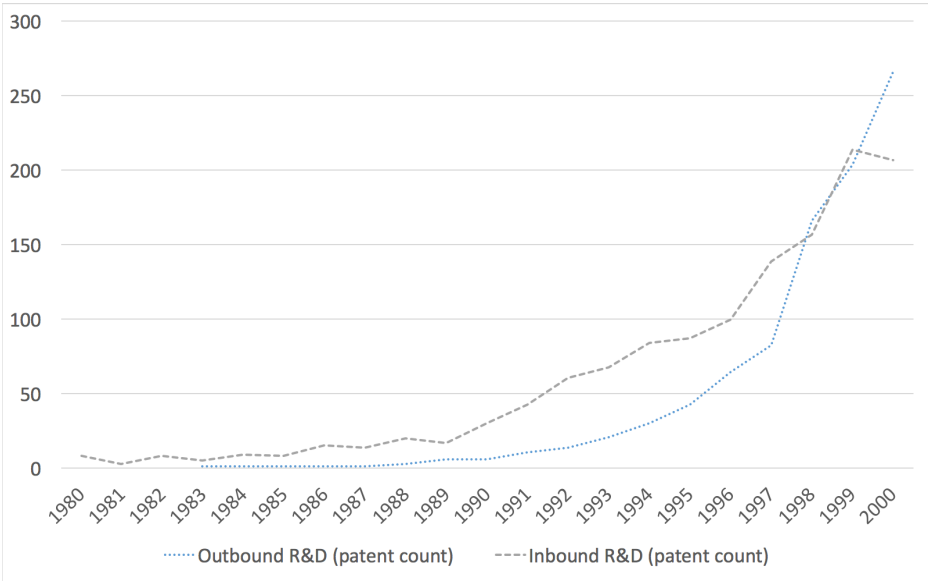



**Figure 13. Inbound and outbound R&D in Taiwan (patent count), 1980-2000**



By 1973, the Taiwanese policy on FDI favored firms with technology-intensive products and processes. However, unlike Korea, the Taiwanese strategy was to invite FDI along with policies that promote backward linkages, tapping on small local suppliers through subcontracting agreements and by having local content requirements (Aw, 2003). Specifically, FDI was used to transfer technology to their local suppliers by promoting backward linkages and local content requirement. The government, in exchange, guaranteed an efficient subcontracting network, relatively cheap educated labor, and reduction of production cost. As such, the foreign firms cooperated by providing training on technical skills and know-how and also on management skills.

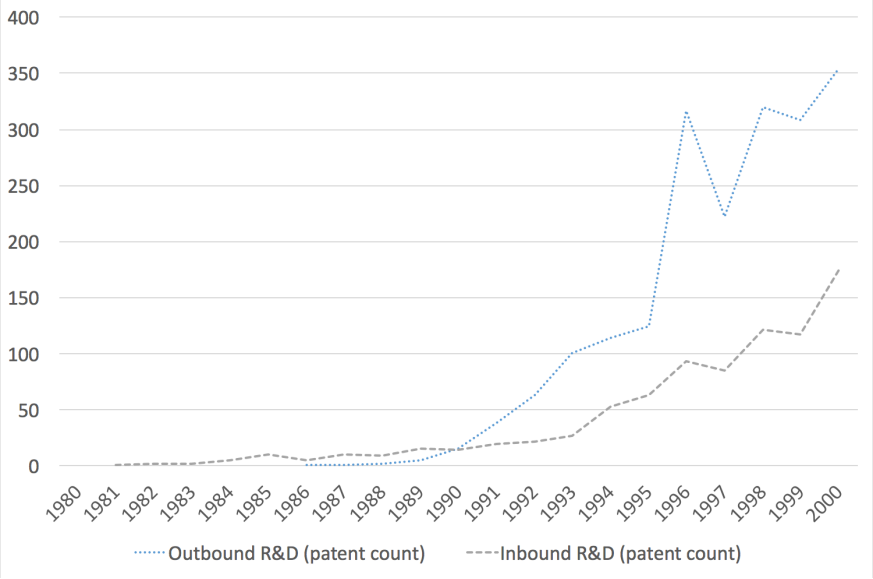
Moreover, as the reputation of Taiwanese firms as low-cost and efficient suppliers, foreign buyers eventually opened offices in Taiwan to facilitate the transactions with local suppliers. In addition, these offices also facilitated the flow of product designs and technical assistance from the foreign firms or buyers who want the products to meet their quality standards and specifications.

## 1.c. Observation 3: More outbound R&D since 1990 (Korea) and 1998 (Taiwan)

Lee and Kim (2010) identified mid-1980s to mid-1990s as the period of rapid catch up for Korean firms. Lee and Plummer (1992) also observed that outward FDI from Korea grew more rapidly than inward FDI in the same period. Figure 10 shows that outbound R&D patents were able to exceed inbound R&D in the 1990s. This trend in 1990 is similar with the point transitioning between Stage 3 and Stage 4 in the IDP, where the outflow exceeds in the inflow of investments. As such, this suggests that in terms of the globalization of R&D variables, Korea has reached Stage 4 in the 1990s. This reflects the performance of overseas R&D centers owned by Korean firms. By 1994, OECD recorded that Korean firms owned 51 R&D centers overseas which were opened to access foreign knowledge (as cited in Lee and Kim, 2010). Innovation activity by the *chaebols* expanded abroad as their R&D laboratories abroad monitor changes in the technological frontier and building alliances with local firms and R&D networks. Some of these big Korean firms establishing outbound R&D include LG (in Tokyo, California, Chicago, Germany, and Ireland), Samsung (in San Jose, Boston, Tokyo, Osaka, London, Frankfurt, and Moscow) (Lee and Kim, 2010).

However, while the inbound and outbound R&D trends showed a rather consistently increasing gap in favor of the latter, the FDI flows (Figure 3) show that FDI inflow was actually decreasing in this period, only to be changed in 1997, after the IMF Financial Crisis led Korea to open to foreign capital. This trend was only reversed in 2006 with the consistent growth of FDI outflow and the subsequent decline in the FDI inflow. This suggests that while there was a surge of FDI inflow after the financial crisis, overseas R&D centers owned by Korean firms remained to be more productive, thus their outbound R&D remained higher than inbound R&D patents (Figure 10).

**Figure 14. Patent counts of inbound and outbound R&D in Korea, 1980-2000**




On the other hand, despite the fact that there has been more outbound R&D since the 1990s, the patenting activities of foreign firms in Korea has also

been increasing, albeit at a slower pace. In particular, as a result of the 1997 Asian Financial Crisis, the reforms introduced in Korea included the Foreign Investment Promotion Act in 1998, which provided for improved support and incentives for foreign investors. This could possibly explain the continued increase of inbound R&D patent count in the 1990s.

This pattern of initially higher rates of inbound R&D, followed by an increase in the outbound R&D reflects the phases of economic development in the investment development theory. This theory proposes that at the early stages of development, a country receives inward FDI, and as the country grows, they start to generate outward FDI (Dunning and Narula, 1994). Existing literature notes that various reasons for the outward FDI from a then emerging country like Korea include changing comparative advantages, profitability, and other macroeconomic factors such as trade surplus, wages, and protectionism (Lee and Plummer, 1992). This pattern of the outbound R&D overtaking inbound R&D proposes that accessing foreign knowledge was also a factor for the increase in FDI outflow.

Increase in the outbound R&D reflects the improvement in the capability of local firms to send capital abroad to conduct R&D activities or to purchase shares of foreign firms with significant technological capabilities. Taiwan also shows a similar trend with Korea: the patent count of outbound R&D being more than inbound R&D around 1998. By the 1990s, Taiwan's

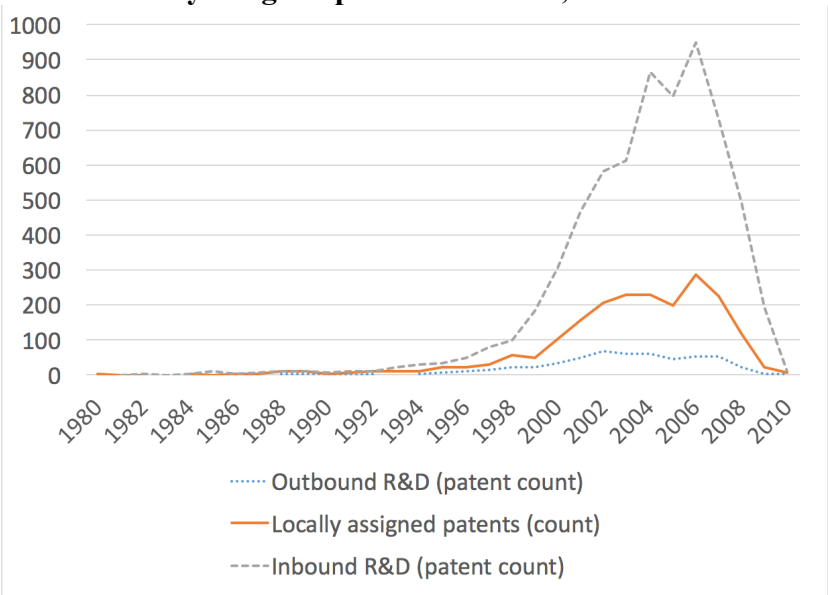
outbound R&D was growing at a faster average rate of 50% compared to the patents applied by foreign firms investing inside Taiwan which was growing at an average rate of 25%. Eventually, outbound R&D exceeded inbound R&D in 1999, and has then remained in that state well into the 2000s (Figure 12). This stage is parallel to Stages 3 and 4, where the outward flow started to gain a faster track, and eventually exceeded inward flow of investments.

The trends support the existing findings that Taiwan relied on inbound R&D from the FDI inflows to source technology into the country, and the succeeding decline in the share of inbound R&D, in favor of the increasing trend in outbound R&D. In the case of Taiwan, there is evidence in the literature that the contact with foreign companies contributed to higher technical efficiency among Taiwanese firms. Aw (2003) reports that the coefficient estimates of FDI and variables of technology spillover is positive and statistically significant for smaller Taiwanese firms. Specifically, he found that an increase of 10% in the share of foreign firms in an industry improved firm productivity growth by 3%. Moreover, they also found evidence that there is spillover effect to other firms without FDI. The condition that facilitated this spillover effects from FDI is the presence of local producers in Taiwan that dealt with foreign firms.

## 1.d. Chinese inbound and outbound R&D

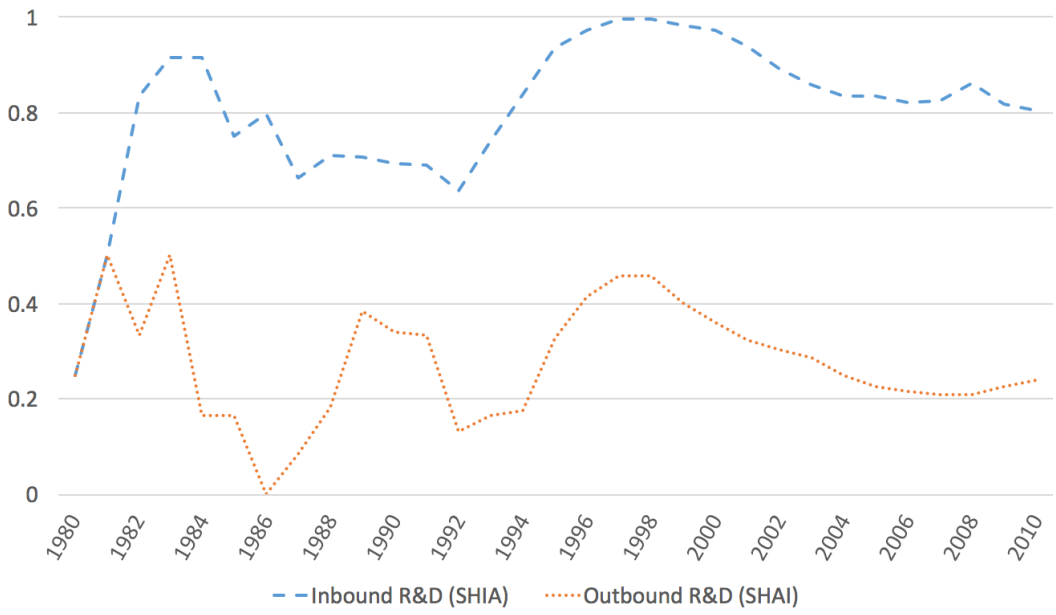
Among the three country cases considered in this study, only the Chinese case showed different characteristics. As presented in Figure 6, inbound R&D patent count has the highest quantity, being more than inbound R&D and outbound R&D. Since the economic reform in 1979, the Chinese government rolled out policies to promote FDI inflow: establishing special economic zones, amending legislations, implementing tax incentives, and some degree of devolving authority from the Central Government (Ran, et al., 2007). Among the three countries considered in this study, it is only in the Chinese case where FDI outflow did not exceed FDI inflow in the period between 1980 and 2010 (Figure 1). This trend is also reflected in the pattern of inbound and outbound R&D of China, where inbound R&D remained higher in China, even higher in comparison with locally assigned patents. This pattern is parallel with the pattern of FDI inflow and outflow for the early stages (1-3) of the investment development path.

**Figure 15. Patent counts of inbound R&D, outbound R&D and locally assigned patents in China, 1980-2010**



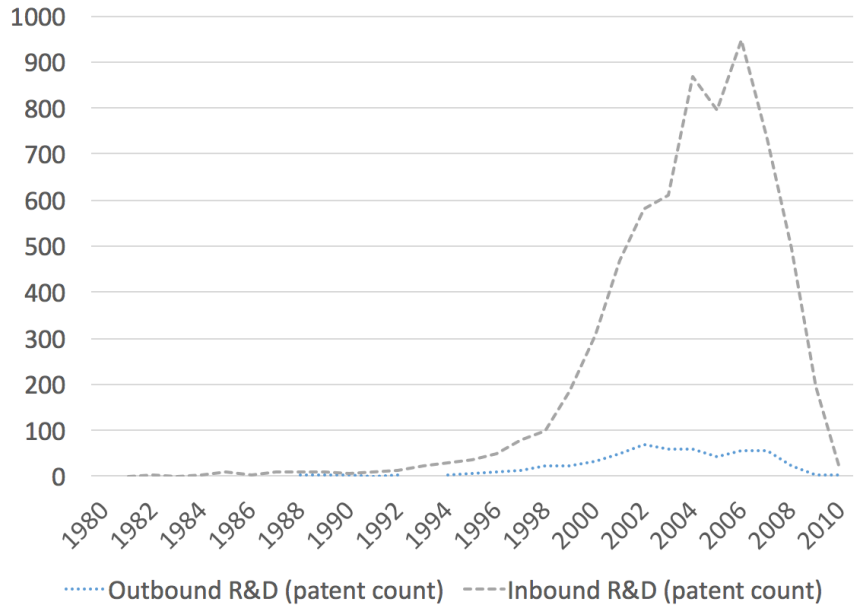

In China, inbound R&D patents (or patents owned by foreign firms) remain to have the most number. From 1980s to 1992, inbound R&D patents and locally owned patents were about the same amount, but since 1992, the growth rate of patents owned by foreign firms invented in China increased, and has since then been higher than both the locally owned patents in China and the outbound R&D. Multinational companies from developed countries set up R&D centers in China in order to cater to Chinese customers and capture a huge market in China more rapidly (Lee and Wang, 2010). The recent inflow of foreign R&D activities to China is motivated by the known benefits of performing R&D within the proximity of existing manufacturing sites, and to access China's supply of skilled engineers (Sun, et al., 2007).

**Figure 16. Inbound and Outbound R&D shares in China, 1980-2010**




Nevertheless, Figure 17 shows that outbound R&D patents have been growing albeit at a slower pace. However, as noted by Yang, Jiang, Kang and Ke (2009), the FDI outflow by Chinese companies were motivated by the search for natural resources (natural resource-seeking investments) and to move out production in mature industries (efficiency-seeking investments). The graphs show that strategic asset-seeking investment was not part of the motivations of the firms.

**Figure 17. Patent counts of inbound and outbound R&D in China, 1980-2010**




Using the terminologies from IDP, this patterns of high inward flow and slow growth rate of outbound flow are characteristics of Stage 2 economies. Considering the FDI flows of China (Figure 1), FDI outflow has actually been growing since the 1990s, but at a slower rate. On the other hand, FDI inflow increased dramatically in the early 1990s, and has since then been declining. This trend of gradual but consistent increase in outflow and initial high inflow followed by consistent downward trend does not have a specific combination in the stages considered in IDP. While consistent but slow growth of outward flow can be found in Stage 2, a gradual decline in inflow can be compared to the plateau of inward FDI characteristic of Stages 3 to 5.

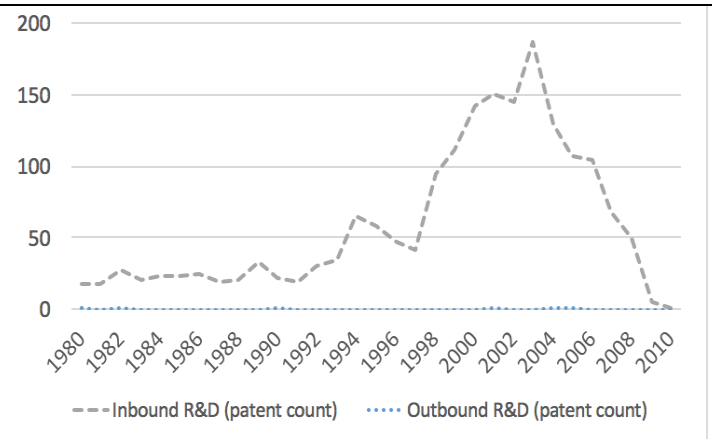
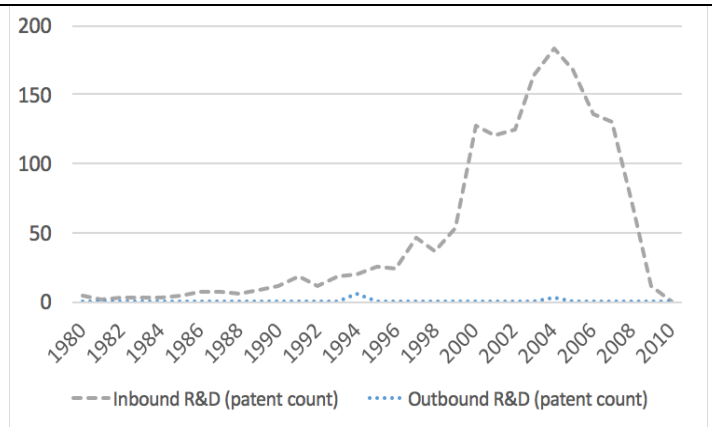
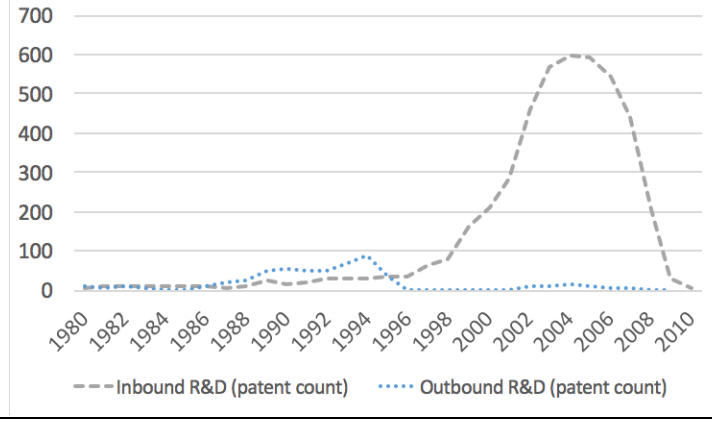
Nevertheless, the FDI flows of China follows a converging trend until 2010, suggesting a dynamic between FDI inflow and FDI outflow of Stage 3.[1]

Juxtaposing the FDI flows and the inbound and outbound R&D of China suggests that while FDI flows match with the pattern in Stage 3 of IDP, the trends of inbound and outbound R&D parallel stage 2 characteristics of high inbound R&D and slow but increasing outbound R&D (Figure 17). This suggests that (1) while Chinese firms are increasingly investing in overseas market, their focus is not on the production of patents (strategic asset-seeking), but on resources and markets (market-seeking) and that the (2) foreign firms investing in China are concerned with protecting their technology by applying for patents.

This trend of higher inbound R&D is also evident in developing countries and those caught in the middle income trap. Table 5 below shows the graphs for three country groups in Latin America (Brazil, Argentina, Mexico), Southeast Asia (Malaysia, Thailand, Philippines) and India. As can be observed, inbound R&D in all the three cases remain more than the outbound R&D from these three groups.

[1] Continuing the FDI flows graph actually shows a convergence between Chinese FDI inflow and outflow (% of GDP) in 2015.

**Table 5. Globalization of R&D trends in three country groups, 1980-2010**

| Country | Graph |
|---|---|
| Latin America |   |
| Southeast Asia |   |
| India |   |

## 1.e. Preliminary Summary

In summary, the trends show that for countries that have already caught up to the developed countries (Korea and Taiwan), both had a declining share of inbound R&D, and had an increasing trend of outbound R&D, which have exceeded the former in the 1990s. This is parallel with the characteristic of FDI flows in Stage 4 of the IDP where the outflow of FDI exceeds that of FDI inflow.

However, their inbound and outbound R&D trends do not necessarily follow the trends of their FDI flows. In the case of Korea, outbound R&D was able to exceed inbound R&D earlier (around 1990), compared with the FDI outflow exceeding FDI inflow (around 2006). The FDI inflow of Korea was particularly high after the 1998 Asian Financial Crisis, and FDI outflow was only able to exceed FDI inflow in 2006; while their outbound R&D patent count has exceeded inbound R&D since 1990. This suggests that while the FDI outflow of Korea was relatively smaller than its FDI inflow, Korean firms pursued strategic asset-seeking investments such as by acquiring foreign firms with strategic technologies or patents.

On the other hand, Taiwan's FDI outflow has been higher than their FDI inflow since 1986, while their outbound R&D exceeded inbound R&D only in 1999. This suggests that Taiwan's outward investment was focusing on

other types of investments such as natural resource-seeking, market-seeking, and efficiency-seeking investments. Nevertheless, outbound R&D eventually exceeded inbound R&D, reflecting the improved capital and technological resources of Taiwanese firms. Moreover, the fact that the outbound R&D rates of both countries have exceeded their inbound R&D rates show that these two countries have similar characteristics with the Stage 4 of the investment development path.

On the other hand, China's FDI flows and globalization of R&D variables show similar trends: with FDI inflow and inbound R&D consistently higher than FDI outflow and outbound R&D, respectively. While FDI inflow showed a spike in mid-1990s, inbound R&D followed with a spike in number of patents in late-1990s. This supports the OECD finding that FDI on production is eventually followed by R&D activities by MNCs. Nevertheless, as the inflows are higher than their respective outflows and with the declining growth rate, the results show that China exhibits the characteristics of the middle stages of growth (around late stage 2 and early stage 3) for the period 1980-2010.

Given this background, it is expected that inbound R&D has contributed to the growth of their respective national innovation systems. From the literature, the growing outflow of investments—particularly in R&D activities as seen in the increasing trend of R&D output (i.e. patents)

overseas—indicate (a) an increase in strategic asset-seeking outward investments by domestic firms; thus (b) there is improved access to ownership advantages such as financial and technological assets of local by the domestic firms.

As there are existing studies that have investigated the role of FDI inflows to the competitiveness or the productivity of local firms (Lee and Plummer, 1992; Aw, 2003), this study will focus on the growth in the technological assets at the national level by considering the national innovation system (NIS). As such, the following section will look at how inbound R&D has influenced the different aspects of the NIS of the three countries: (a) growth in their locally owned patents, (b) the shortening of the cycle time of of their patents, (c) the increased localization of the creation and diffusion of knowledge, and (d) the increased diversification of the patent classes of their patents.

## 2. Results of empirical analysis

Based on the results on the first part, only Korea and Taiwan exhibited a convergence of inbound and outbound R&D from the period between 1980 to 2010. While China exhibits to be still in the earlier part of developing their outbound R&D. This should be interpreted carefully since China has a huge domestic market and as a catching up country, Chinese firms must find little benefit to protect their technologies abroad. On the other hand, Korea and Taiwan are export-oriented countries, and as such it would be in their firms' interest to protect their technologies abroad. Nevertheless, this study only considered Korea and Taiwan in the second part given that only these countries exhibited similar patterns as predicted in the IDP.

Lee (2013) identified three NIS variables significantly related with economic growth: the cycle time of technologies, localization of knowledge creation, and diversification of technology. The number of locally owned patents is also included to cover the quantitative effect of inbound R&D. Following from the findings of Lee's (2013) study that the other two NIS variables of originality and innovator-concentration are not relevant in explaining the success of the emerging countries, these two are not included in this study.

## 2.a. Unit Root Tests, cointegration tests and regression results

The first step in the regression analysis is the identification of the existence of unit roots to test the stationarity of the variables. The results are shown in Table A for Korea and Table B for Taiwan. In order to capture possible time lag differences, this study tests all the hypothesis in time lags of 3 years, 6 years, 8 years and 10 years.

The unit root test results were the basis for the selection of the tests for the bivariate equations. After the selection of tests, the existence of long run-relationships were tested for equations with both I(1) variables and equations with a mix of I(0) and I(1) variables. Johansen Cointegration Test was conducted for estimations using VECM, while Bounds Test was conducted for equations that fit for ARDL. Tables 7, 8, 9, and 10 present the results.

**Table 6. Unit root test results**

| | | Korea | | | | Taiwan | | | |
|---|---|---|---|---|---|---|---|---|---|
| Lag | Var | PP without constant | PP with constant | ADF without constant | ADF with constant | PP without constant | PP with constant | ADF without constant | ADF with constant |
| 3 | ib | -2.637** | -3.803*** | -3.724*** | -3.333*** | -4.179*** | -3.744*** | -6.102*** | -5.704*** |
| 3 | Δib | -15.79*** | -17.222*** | -1.848* | -2.175 | -10.94*** | -12.34*** | -2.049** | -2.044* |
| 3 | ob | -1.002 | -3.835*** | 0.210 | -0.511 | -3.024*** | -5.203*** | -0.179 | -0.965 |
| 3 | Δob | -10.49*** | -10.607*** | -2.772*** | -2.912** | -11.98*** | -12.04*** | -3.588*** | -3.608*** |
| 3 | lass | -1.065 | -1.456 | -0.030 | -1.049 | -1.013 | -1.338 | -1.958** | -.2.169 |
| 3 | Δlass | -2.158** | -2.124 | -2.522** | -2.755** | -2.982*** | -2.922*** | -0.447 | -0.031 |
| 3 | ct | -0.486 | -1.339 | -0.518 | -2.466 | -1.304 | -2.052 | -0.701 | -1.786 |
| 3 | Δct | -4.151*** | -4.100*** | -1.868* | -1.915 | -5.439*** | -5.331*** | -1.033 | -0.889 |
| 3 | loc | 3.464 | 0.926 | 1.360 | 0.370 | 0.402 | -1.338 | -0.209 | -1.440 |
| 3 | Δloc | -4.555*** | -6.246*** | -0.712 | -2.205 | -5.132*** | -5.334*** | -1.136 | -1.221 |
| 3 | div | -4.186*** | -4.832*** | -2.023** | -3.155** | -4.976*** | -6.162*** | -1.471*** | -2.764* |
| 3 | Δdiv | -9.379*** | -9.184*** | -3.808*** | -3.719** | -14.21*** | -14.00*** | -3.832*** | -3.756*** |
| 6 | ib | -2.883*** | -4.128*** | -0.329 | -2.504 | -4.169*** | -3.702** | -2.014** | -1.965* |
| 6 | Δib | -14.25*** | -16.197*** | -3.488*** | -3.074** | -10.91*** | -13.64*** | -3.048*** | -3.236** |
| 6 | ob | -1.212 | -4.102*** | 1.275 | -0.889 | -3.139*** | -5.285*** | 1.735 | 0.523 |
| 6 | Δob | -12.32*** | -13.289*** | -2.032** | -2.700* | -14.01*** | -14.64*** | -1.450* | -1.990 |
| 6 | lass | -1.072 | -1.438 | -0.643 | -1.114 | -1.122 | -1.457 | -2.018** | -2.502 |
| 6 | Δlass | -1.804* | -1.763 | -1.099* | -1.279 | -3.117*** | -3.066** | -2.113** | -1.928* |
| 6 | ct | -0.483 | -1.398 | 2.181 | 0.179 | -1.182* | -2.034 | -0.276 | -2.135 |
| 6 | Δct | -4.335*** | -4.273*** | -1.285 | -0.885 | -5.461*** | -5.384*** | -0.766 | -0.697 |
| 6 | loc | 3.212*** | 0.894 | 1.026 | -0.043 | 0.225 | -1.352 | -0.306 | -1.729 |
| 6 | Δloc | -4.885*** | -6.215*** | -0.429* | -1.790 | -5.407*** | -5.504*** | -1.137 | -1.167* |
| 6 | div | -4.215*** | -4.911*** | -0.900 | -1.497 | -5.358*** | -6.162*** | 0.080 | -1.116 |
| 6 | Δdiv | -14.06*** | -13.805*** | -2.799*** | -2.732** | 21.49*** | -21.77*** | -3.120*** | -3.373** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | ib | -2.966*** | -4.213*** | -0.426 | -2.535* | -4.132*** | -3.679*** | -6.024*** | -5.789*** |
| 8 | Δib | -13.66*** | -15.736*** | -2.704*** | -2.386 | -10.86*** | -14.66*** | -2.570** | -1.815 |
| 8 | ob | -1.384 | -4.240*** | 1.552 | -0.855 | -3.218*** | -5.343*** | 1.519 | 1.022 |
| 8 | Δob | -13.49*** | -16.104*** | -1.802* | -3.450*** | -14.86*** | -16.05*** | 0.094 | -0.428* |
| 8 | lass | -1.055 | -1.393 | -2.400** | -2.545* | -1.124 | -1.439 | -1.473 | -2.046 |
| 8 | Δlass | -1.682* | -1.641 | -0.898* | -0.973 | -3.087*** | -3.040** | -1.445* | -1.495 |
| 8 | ct | -0.483 | -1.404 | 1.505 | -0.261 | -1.163 | -2.034 | -0.113 | -2.985** |
| 8 | Δct | -4.411*** | -4.341*** | 0.000 | 0.581 | -5.498*** | -5.421*** | -1.074 | -0.727* |
| 8 | loc | 3.079 | 0.887 | 0.586 | -0.112 | 0.163 | -1.358 | -0.522 | -1.803 |
| 8 | Δloc | -5.103*** | -6.231*** | -0.306 | -3.460*** | -5.555*** | -5.576*** | -1.035 | -1.133 |
| 8 | div | -4.302*** | -4.926*** | -0.697 | -1.232 | -5.649*** | -6.170*** | 1.207 | 0.153 |
| 8 | Δdiv | -14.28*** | -14.032*** | -1.953** | -1.872 | -24.02*** | 25.13*** | -2.029** | -2.280* |

**Table 7. Bounds Test Results (ARDL) and Johansen Cointegration Test Results (VECM) (H1-H8)**

| | | (1) IB→LASS | | (2) LASS → IB | | (3) IB→ CT | | (4) CT → IB | | (5) IB→ LOC | | (6) LOC → IB | | (4) IB→DIV | | (8) DIV → IB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** |
| 3 | KR | F = 2.21 t = -2.10 | No | F = 0.84 t = -0.97 | No | F = 7.804 t = -0.79 | Yes | F = 0.34 t = -0.24 | No | F = 4.07 t = -0.70 | No | F = 0.30 t = -0.46 | No | VAR | VAR | VAR | VAR |
| 3 | TW | F = 1.81 t = -1.90 | No | F = 8.15 t = -2.99 | Yes | F = 0.696 t = -1.14 | No | F = 12.85 t = -3.36 | Yes | F = 1.718 t = -1.32 | No | F = 11.04 t = -2.60 | Yes | VAR | VAR | VAR | VAR |
| 6 | KR | r = 1 3.602* | Yes | r = 1 3.60* | Yes | F = 0.696 t = -1.14 | No | F = 5.57 t = -3.23 | Yes | r = 1 3.018* | Yes | r = 1 3.01* | Yes | F = 1.65 t = -1.77 | No | VAR | VAR |
| 6 | TW | F = 7.28 t = -3.81 | Yes | F = 2.61 t = -2.06 | No | F = 1.807 t = -1.89 | No | F = 4.28 t = -0.85 | Yes | F = 0.998 t = -1.29 | Yes | F = 3.70 t = -2.24 | No | VAR | VAR | VAR | VAR |
| 8 | KR | None | No | NC | No | F = 56.18 t = -10.0 | Yes | F = 12.07 t = -4.85 | Yes | r = 1 2.733* | Yes | r = 1 2.73* | Yes | F = 1.04 t = 1.441 | No | VAR | VAR |
| 8 | TW | F = 1.43 t = -1.68 | No | F = 1.09 t = -0.89 | No | F = 0.580 t = -0.67 | No | F = 2.76 t = -1.06 | No | F = 3.972 t = -2.62 | Yes | F = 4.20 t = -1.00 | Yes | VAR | VAR | VAR | VAR |

**Table 8. Bounds Test Results (ARDL) and Johansen Cointegration Test Results (VECM) (H9-H16)**

| | | (9) OB→LASS | | (10) LASS → OB | | (11) OB → CT | | (12) CT → OB | | (13) OB→ LOC | | (14) LOC → OB | | (15) OB → DIV | | (16) DIV → OB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** |
| 3 | KR | r = 1 3.26* | Yes | r = 1 3.265* | Yes | NC | NC | None | No | r =1 1.37* | Yes | r = 1 1.37* | Yes | F = 5.47 t = -3.29 | Yes | F = 2.282 t = -1.97 | No |
| 3 | TW | NC | NC | None | No | r = 0 12.43* | Yes | r = 0 12.4* | Yes | r = 0 4.55* | Yes | r = 0 4.55* | Yes | F = 2.26 t = -2.09 | No | F = 0.774 t = -0.302 | No |
| 6 | KR | r = 0 8.47* | Yes | r = 0 8.478* | Yes | r = 1 3.67* | Yes | r = 1 3.671* | Yes | r = 1 0.74* | Yes | r = 1 0.746* | Yes | F = 2.37 t = -2.07 | No | F= 0.940 t = -0.799 | No |
| 6 | TW | NC | NC | None | No | r = 1 2.54* | Yes | r = 1 2.549* | Yes | r = 0 9.08* | Yes | r = 0 9.080* | Yes | F = 1.44 t = -1.61 | No | F = 3.628 t = -1.774 | No |
| 8 | KR | r = 0 13.89* | Yes | r = 0 13.891* | Yes | r = 1 3.25* | Yes | r = 1 3.251* | Yes | r = 1 0.24* | Yes | r = 1 0.241* | Yes | F = 0.70 t = -1.09 | No | F = 0.286 t = -0.410 | No |
| 8 | TW | NC | NC | None | No | r = 1 3.26* | Yes | r = 1 3.264* | Yes | r = 0 11.7* | Yes | r = 0 11.72* | Yes | F = 1.26 t = -1.42 | No | F = 1.655 t = -0.249 | No |

**Table 9. Bounds Test Results (ARDL) and Johansen Cointegration Test Results (VECM) (H17-H22)**

| | | (17) LASS → CT | | (18) LASS → LOC | | (19) LASS → DIV | | (20) CT → LASS | | (21) CT → LOC | | (22) CT → DIV | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** |
| 3 | KR | None | No | r = 1<br>0.741* | Yes | F = 6.522<br>t = -3.551 | Yes | None | No | r = 0<br>11.669* | Yes | r = 0s<br>11.66* | Yes |
| 3 | TW | r = 1<br>1.863* | Yes | r = 1<br>1.664* | Yes | F = 5.320<br>t = -3.320 | Yes | r = 1<br>1.863* | Yes | r = 0<br>5.156* | Yes | F =5.243<br>t = -3.238 | Yes |
| 6 | KR | None | No | r = 0<br>14.54* | Yes | F =<br>t = | NC | None | No | None | No | None | No |
| 6 | TW | r = 1<br>2.230* | Yes | r = 1<br>0.853* | Yes | F = 4.875<br>t = -2.95 | Yes | r = 1<br>2.230* | Yes | None | No | F = 6.235<br>t = -3.531 | Yes |
| 8 | KR | None | No | r = 1<br>0.391 | Yes | F = 0.199<br>t =0. 019 | NC | None | No | None | No | None | No |
| 8 | TW | None | No | None | No | F = 4.156<br>t = -2.879 | Yes | None | No | r = 1<br>0.517* | Yes | F = 3.290<br>t = -2.290 | Yes |

**Table 10. Bounds Test Results (ARDL) and Johansen Cointegration Test Results (VECM) (23-H28)**

| | | (23) LOC → LASS | | (24) LOC → CT | | (25) LOC → DIV | | (26) DIV → LASS | | (27) DIV → LOC | | (28) DIV → CT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** | **F stat / trace stat** | **Co.** |
| 3 | KR | r = 1<br>0.741* | Yes | r = 0<br>11.669* | Yes | F = 7.073<br>t =-3.737 | Yes | F = 2.999<br>t = -1.692 | No | F = 0.990<br>t = 1.302 | No | F = 2.203<br>t = -2.093 | No |
| 3 | TW | r = 1<br>1.664* | Yes | r = 0<br>5.156* | Yes | F = 4.812<br>t =-3.088 | Yes | F = 1.394<br>t = -1.300 | No | F = 1.479<br>t = -1.274 | No | F = 0.792<br>t = -0.539 | No |
| 6 | KR | r = 0<br>14.549* | Yes | None | No | F = 2.086<br>t = -1.996 | No | F = 0.310<br>t = -0.454 | No | F = 0.057<br>t = -.062 | No | F = 5.054<br>t = -2.950 | Yes |
| 6 | TW | r = 1<br>0.853* | Yes | None | No | F = 4.339<br>t = -2.900 | Yes | F = 11.94<br>t = -1.834 | Yes | F = 3.062<br>t = -1.310 | No | F = 3.266<br>t = -2.051 | No |
| 8 | KR | r = 1<br>0.391* | Yes | None | No | F = 1.755<br>t = -1.775 | No | F = 1.915<br>t = 1.090 | No | F = 0.011<br>t = 0.056 | No | F = 1.306<br>t = -1.609 | No |
| 8 | TW | None | No | r = 1<br>0.517* | Yes | F = 6.099<br>t = -3.486 | Yes | F = 0.616<br>t = -0.455 | No | F = 0.443<br>t = -0.043 | No | F = 5.209<br>t = -1.316 | Yes |

## Inbound R&D and NIS Variables

**Table 11. Regression Test Results for ARDL tests and VECM tests (H1-H8)**

| | | (1) IB→LASS | | (2) LASS → IB | | (3) IB→ CT | | (4) CT → IB | | (5) IB → LOC | | (6) LOC→IB | | (7) IB→ DIV | | (8) DIV→IB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** |
| 3 | KR | I(0), I(1) ARDL | NC (Btest) | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | -18.44 (0.685) | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | -2.128 (0.436) | I(1), I(0) ARDL | NC | I(0), I(0) VAR | 0.649 (0.420) | I(0), I(0) VAR | 1.004 (0.316) |
| 3 | TW | I(0), I(1) ARDL | -7608.5 (0.180) | I(1), I(0) ARDL | -9.05 (0.767) | I(0), I(1) ARDL | 6.934 (0.257) | I(1), I(0) ARDL | 0.032 (0.226) | I(0), I(1) ARDL | -0.142 (0.482) | I(1), I(0) ARDL | -0.897 (0.333) | I(0), I(0) VAR | 2.643* (0.104) | I(0), I(0) VAR | 0.019 (0.889) |
| 6 | KR | I(1), I(1) VECM | 0.0133 (0.52) | I(1), I(1) VECM | -0.757*** (0.000) | I(0), I(1) ARDL | NC (Btest) | I(1), I(0) ARDL | 0.006 (0.283) | I(1), I(1) VECM | -0.06* (0.08) | I(1), I(1) VECM | -0.687*** (0.000) | I(1), I(0) ARDL | NC Btest | I(1), I(0) ARDL | 0.005 (0.884) |
| 6 | TW | I(0), I(1) ARDL | -9285.9 (0.061) | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | 12.180 (0.013) | I(1), I(0) ARDL | -0.027 (0.824) | I(0), I(1) ARDL | -0.400* (0.084) | I(1), I(0) ARDL | NC | I(0), I(0) VAR | -0.547 (0.590) | I(0), I(0) VAR | 0.015 (0.900) |
| 8 | KR | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(0), I(1) ARDL | 61.662 (0.00) | I(1), I(0) ARDL | 0.015 (0.000) | I(1), I(1) VECM | -0.515*** (0.00) | I(1), I(1) VECM | -0.615*** (0.014) | I(1), I(0) ARDL | NC Btest | I(1), I(0) ARDL | 0.119 (0.010) |
| 8 | TW | I(0), I(1) ARDL | -7669.1 (0.300) | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | 19.994 (0.351) | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | -0.053*** (0.001) | I(1), I(0) ARDL | -1.017 (0.388) | I(0), I(0) VAR | -0.4292 (0.780) | I(0), I(0) VAR | 0.450 (0.502) |

## Outbound R&D and NIS Variables

**Table 11. Regression Test Results for ARDL tests and VECM tests (H9-H16)**

| | | (9) OB→LASS | | (10) LASS → OB | | (11) OB → CT | | (12) CT → OB | | (13) OB→ LOC | | (14) LOC → OB | | (15) OB → DIV | | (16) DIV → OB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** |
| 3 | KR | I(1), I(1) VECM | -0.098 (0.14) | I(1), I(1) VECM | -1.259*** (0.004) | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.011 (0.790) | I(1), I(1) VECM | -1.600*** (0.000) | I(1), I(0) ARDL | 0.151 (0.401) | I(0), I(1) ARDL | 0.151 (0.401) |
| 3 | TW | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.02*** (0.010) | I(1), I(1) VECM | -0.110 (0.632) | I(1), I(1) VECM | -0.030 (0.416) | I(1), I(1) VECM | -0.171* (0.09) | I(1), I(0) ARDL | -0.061 (0.766) | I(0), I(1) ARDL | 1.469 (0.764) |
| 6 | KR | I(1), I(1) VECM | -0.218* (0.10) | I(1), I(1) VECM | -0.0427 (0.232) | I(1), I(1) VECM | -0.159 (0.244) | I(1), I(1) VECM | -3.103 (0.000) | I(1), I(1) VECM | -0.01 (0.901) | I(1), I(1) VECM | -1.533 (0.003) | I(1), I(0) ARDL | -0.721 (0.547) | I(0), I(1) ARDL | -0.721 (0.547) |
| 6 | TW | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.14*** (0.012) | I(1), I(1) VECM | -0.14* (0.10) | I(1), I(1) VECM | -0.10** (0.048) | I(1), I(1) VECM | -0.342** (0.031) | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | 0.772 (0.053) |
| 8 | KR | I(1), I(1) VECM | -0.433** (0.031) | I(1), I(1) VECM | -0.073 (0.886) | I(1), I(1) VECM | -0.179 (0.454) | I(1), I(1) VECM | -6.620 (0.004) | I(1), I(1) VECM | -0.194 (0.160) | I(1), I(1) VECM | -3.559 (0.000) | I(1), I(0) ARDL | -0.991 (0.722) | I(0), I(1) ARDL | -0.991 (0.722) |
| 8 | TW | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.233** (0.005) | I(1), I(1) VECM | -0.185 (0.508) | I(1), I(1) VECM | -0.157 (0.122) | I(1), I(1) VECM | -0.578** (0.035) | I(1), I(0) ARDL | -0.171 (0.784) | I(0), I(1) ARDL | 2.625 (0.784) |

**Among NIS Variables**

**Table 13. Regression Test Results for ARDL tests and VECM tests (H17-H22)**

| | | (17) LASS → CT | | (18) LASS → LOC | | (19) LASS → DIV | | (20) CT → LASS | | (21) CT → LOC | | (22) CT → DIV | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** |
| 3 | KR | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.137 (0.183) | I(1), I(0) ARDL | -2.15 (0.897) | I(1), I(1) VECM | NC | I(1), I(1) VECM | 0.043 (0.088) | I(1), I(0) ARDL | -0.026 (0.391) |
| 3 | TW | I(1), I(1) VECM | 0.225 (0.000) | I(1), I(1) VECM | 0.172 (0.001) | I(1), I(0) ARDL | 0.000 (0.017) | I(1), I(1) VECM | -0.316*** (0.007) | I(1), I(1) VECM | -0.226 (0.116) | I(1), I(0) ARDL | -0.039 (0.112) |
| 6 | KR | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.392 (0.210) | I(1), I(0) ARDL | NC | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(0) ARDL | -0.019 (0.897) |
| 6 | TW | I(1), I(1) VECM | 0.083 (0.570) | I(1), I(1) VECM | 0.259 (0.023) | I(1), I(0) ARDL | 0.000 (0.047) | I(1), I(1) VECM | -0.905*** (0.001) | I(1), I(1) VECM | NC | I(1), I(0) ARDL | -0.033*** (0.015) |
| 8 | KR | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.926 (0.235) | I(1), I(0) ARDL | NC | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(0) ARDL | 0.279 (0.240) |
| 8 | TW | I(1), I(1) VECM | NC | I(1), I(1) VECM | NC | I(1), I(0) ARDL | 0.000 (0.132) | I(1), I(1) VECM | NC | I(1), I(1) VECM | -0.865* (0.061) | I(1), I(0) ARDL | -0.040** (0.031) |

**Table 14. Regression Test Results for ARDL tests and VECM tests (H23-H28)**

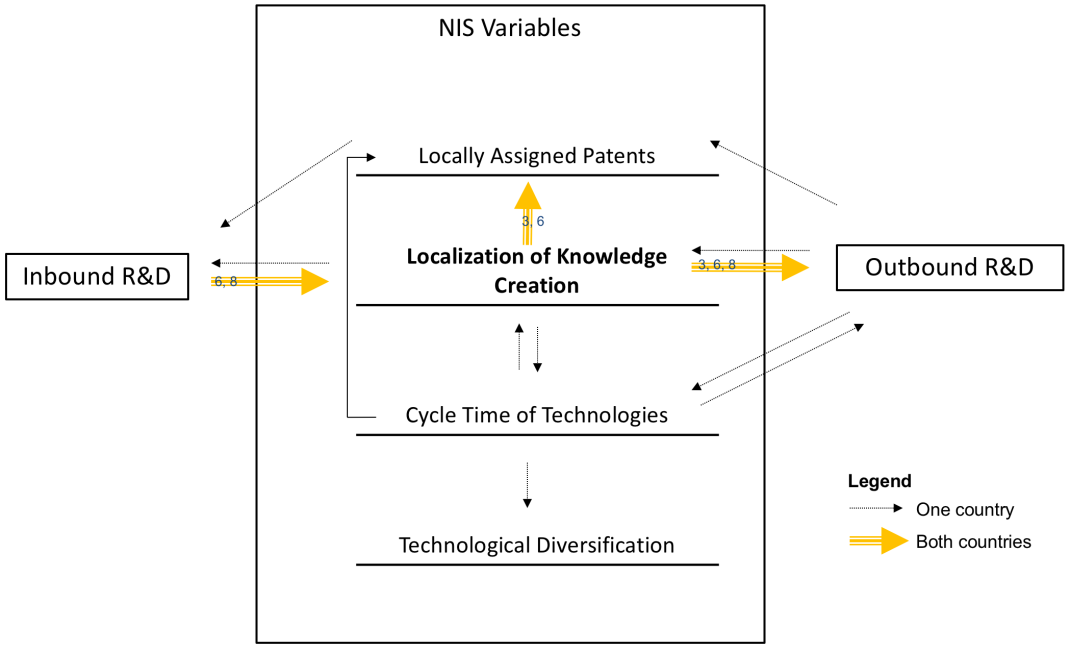
| | | (23) LOC → LASS | | (24) LOC → CT | | (25) LOC → DIV | | (26) DIV → LASS | | (27) DIV → LOC | | (28) DIV → CT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lag** | **Country** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** | **type of test** | **ECT** |
| 3 | KR | I(1), I(1) VECM | -0.468*** (0.000) | I(1), I(1) VECM | -0.055** (0.055) | I(1), I(0) ARDL | -1.099 (0.239) | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC |
| 3 | TW | I(1), I(1) VECM | -0.247** (0.053) | I(1), I(1) VECM | 0.098 (0.545) | I(1), I(0) ARDL | 1.222 (0.092) | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC |
| 6 | KR | I(1), I(1) VECM | -0.976*** (0.011) | I(1), I(1) VECM | NC | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | -11.0 (0.013) |
| 6 | TW | I(1), I(1) VECM | -1.051*** (0.000) | I(1), I(1) VECM | NC | I(1), I(0) ARDL | 1.081 (0.026) | I(0), I(1) ARDL | -8588 (0.594) | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC |
| 8 | KR | I(1), I(1) VECM | -2.554*** (0.004) | I(1), I(1) VECM | NC | I(1), I(0) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC |
| 8 | TW | I(1), I(1) VECM | NC | I(1), I(1) VECM | 1.359 (0.000) | I(1), I(0) ARDL | 0.619 (0.009) | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | NC | I(0), I(1) ARDL | -5.445 (0.724) |

Table 15 summarizes the relationships that were present in both countries and with more time lags.

**Table 15. Summary of the relationships with significant values**

| | Hypothesis | Country | Lags | Type of test, significance |
|---|---|---|---|---|
| Inbound R&D | H2: Locally assigned patents → inbound R&D | Korea | 6 | VECM, significant at 1% level |
| | H5: Inbound R&D → Localization | Korea | 6, 8 | VECM and ARDL, significant at 1% level |
| | | Taiwan | 6, 8 | |
| | H6: Localization → inbound R&D | Korea | 6, 8 | VECM, significant at 1% level |
| NIS Variables | H20: Cycle Time of Technology → locally assigned patents | Taiwan | 3, 6 | VECM, significant at 1% level |
| | H21: Cycle Time of Technology → localization of knowledge creation | Taiwan | 8 | VECM, significant at 10% level |
| | H22: Cycle Time of Technology → diversification | Taiwan | 6, 8 | ARDL, significant at 1% level |
| | H23: Localization of knowledge creation → locally assigned patents | Korea | 3, 6 | VECM, significant at 1% level |
| | | Taiwan | 3 | |
| | H24: Localization of knowledge creation → cycle time of technologies | Korea | 3 | VECM, significant at 5% level |
| Outbound R&D | H9: Outbound R&D → locally assigned patents | Korea | 6, 8 | VECM, significant at 5% level |
| | H11: Outbound R&D → cycle time of technologies | Taiwan | 3, 6, 8 | VECM, significant at 1% level |
| | H12: Cycle time of technologies → outbound R&D | Taiwan | 6 | VECM, significant at 10% level |
| | H13: Outbound R&D → localization of knowledge creation | Taiwan | 6 | VECM, significant at 10% level |
| | H14: Localization of knowledge creation → outbound R&D | Korea | 3, 6 | VECM, significant at 1% level |
| | | Taiwan | 3, 6, 8 | VECM, significant at 5% level |

**Figure 18. The bigger picture – long-run relationships among the variables**




## 2.b. Localization of knowledge creation and locally assigned patents

Among the NIS variables, localization of knowledge creation showed evidence of being influenced by inbound R&D, and also influencing outbound R&D. Before discussing its relation with the globalization of R&D variables, it should be noted that among the tests conducted for the relationship among NIS variables, only the long-run relationship from the localization of knowledge creation to locally assigned patents showed evidence for both country cases, and at two time lags.

**Figure 19. Localization of knowledge creation and locally assigned patents in Korea, 1980-2010**

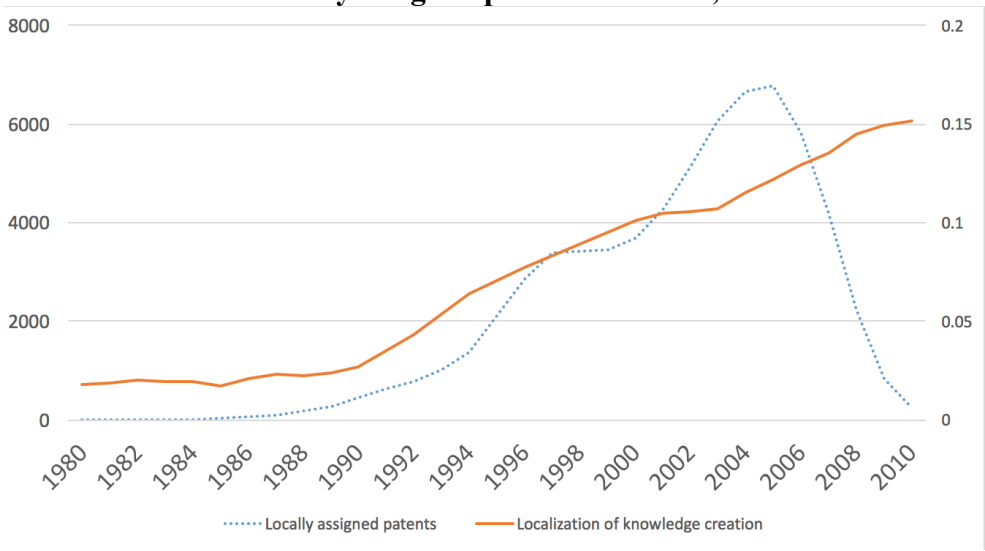
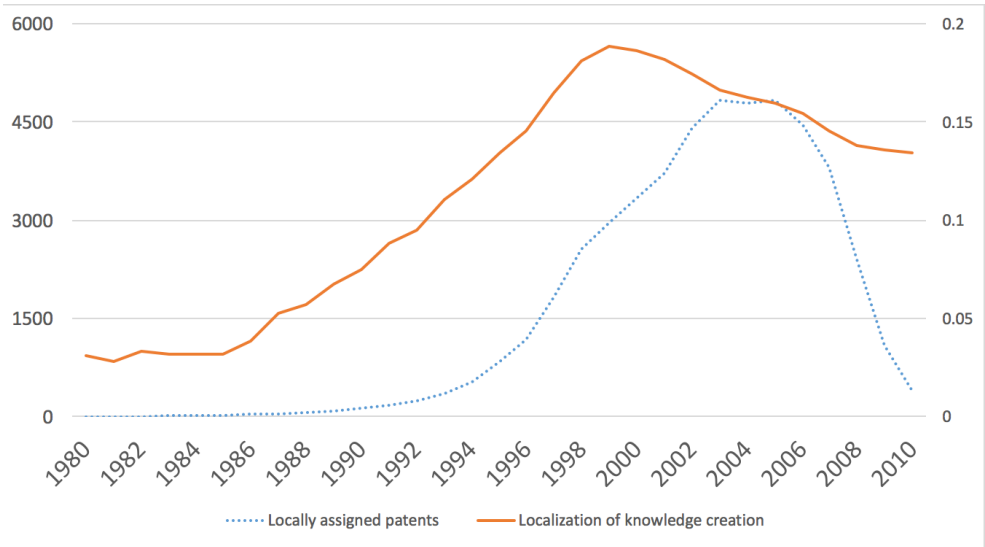



**Figure 20. Localization of knowledge creation and locally assigned patents in Taiwan, 1980-2010**




These results suggest that as local firms increasingly depend on patents from the same country for backward citation, the amount of locally assigned patents also increase. An interpretation for this is that as the increase in the

independence of local patents from foreign patents helps increase the probability of firms to apply for patents. A possible reason for this is that the existence of locally assigned patents that can be cited by newer patents increases the access to sources of information, which increases patenting activities by local firms. This is in line with the results of Jaffe, Trajtenberg and Henderson (1993) that knowledge spillovers are more pronounced with geographical proximity.

## 2.c. Inbound R&D and localization of knowledge creation

As can be seen in figures 21 and 22, there are opposite trends for localization of knowledge creation and inbound R&D. That is, i.e. as inbound R&D (share of foreign ownership of locally invented patents) decreases, the localization variable increases. This can be interpreted as the increase in the use of patents owned by firms from the same country as the dependence on foreign ownership of local R&D activities decreases. This can be expected since inbound R&D is the share of foreign ownership of all the patents with inventor address located in Korea or Taiwan. As such, as the share of inbound R&D (SHIA) decreases, it reflects the decrease in the foreign ownership of patents invented in Korea or Taiwan. "If technological catch-up is led more by foreign firms through measures such as FDIs or the creation of subsidiaries of MNCs, a greater reliance is placed on the knowledge base of the parent firm and of the global network. In such a situation,

the process of knowledge localization and diffusion may take a longer time." (Lee, 2013, p. 204)

**Figure 21. Localization of knowledge creation, inbound R&D share and outbound R&D shares in Korea, 1980-2010**

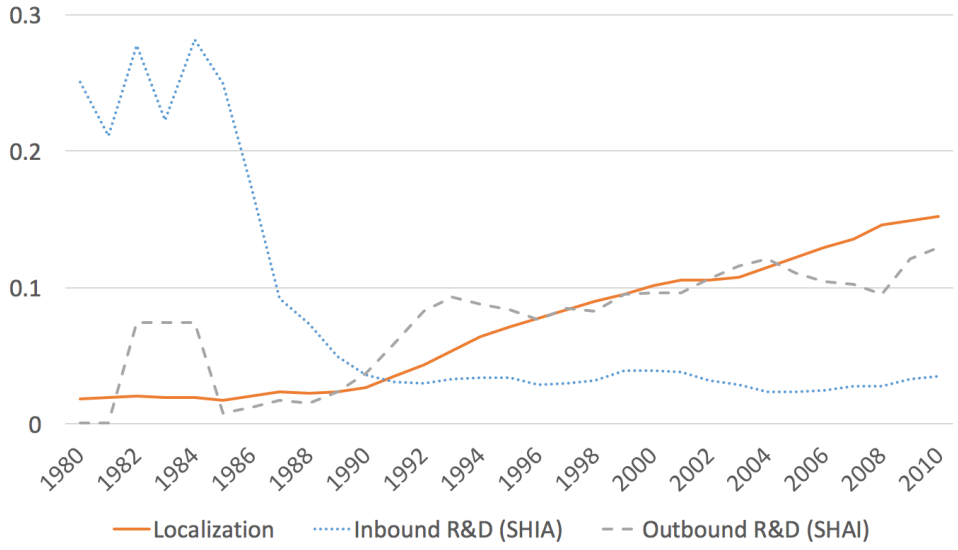
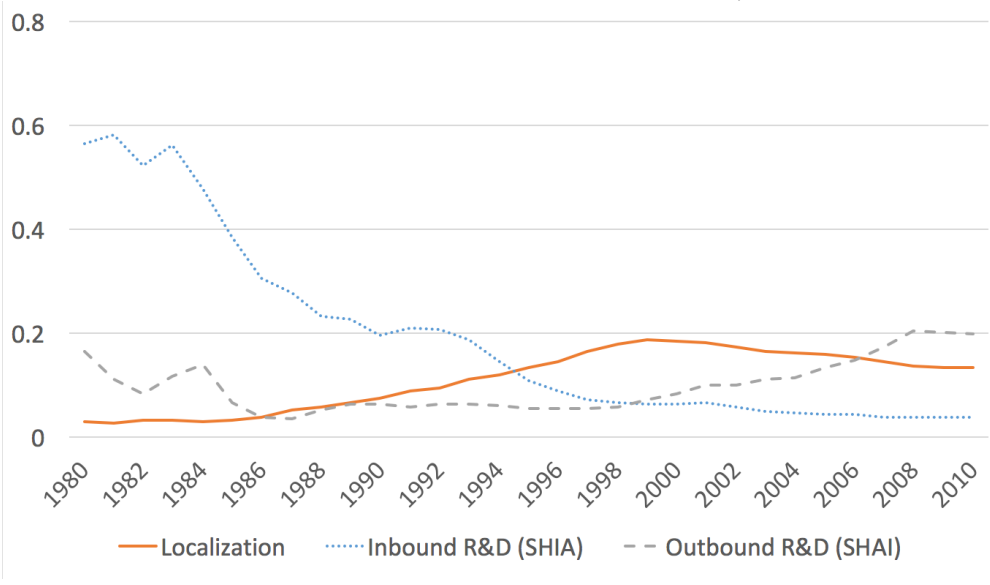



**Figure 22. Localization of knowledge creation, inbound R&D share and outbound R&D shares in Taiwan, 1980-2010**



However, we should be careful in interpreting this as a negative influence of inbound R&D. As figures 23 and 24 show, the trend of the patent count for inbound R&D is actually increasing. As such, the decline in the inbound R&D (SHIA) ratio is due to the faster increase in local ownership or assigneeship of patents invented locally, and not due to a decrease in R&D activities of foreign firms in Korea and Taiwan.

**Figure 23. Localization of knowledge creation and inbound R&D patent count in Korea, 1980-2010**

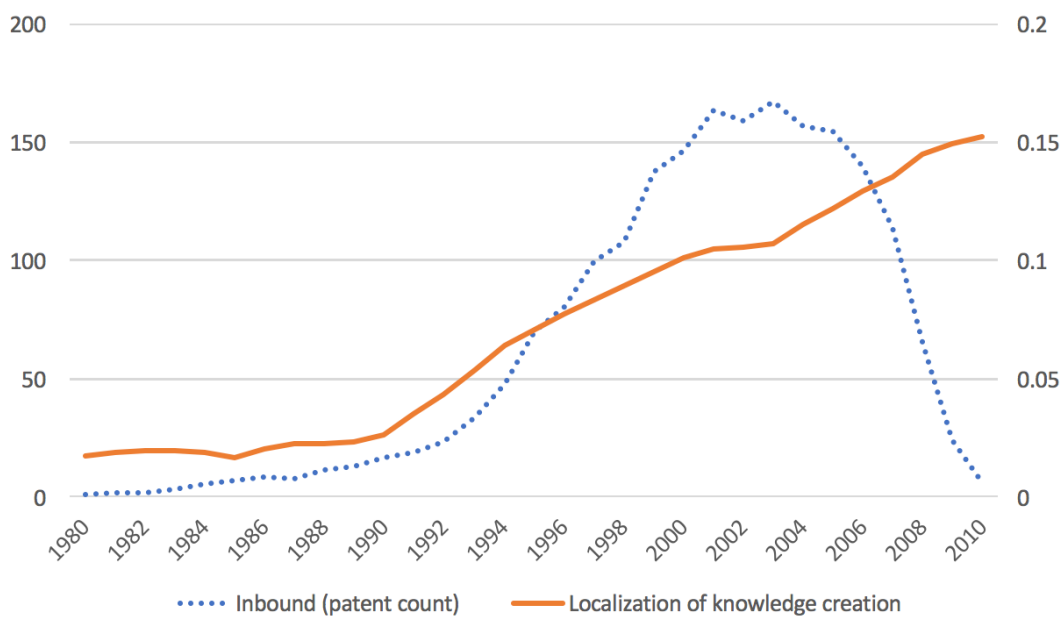
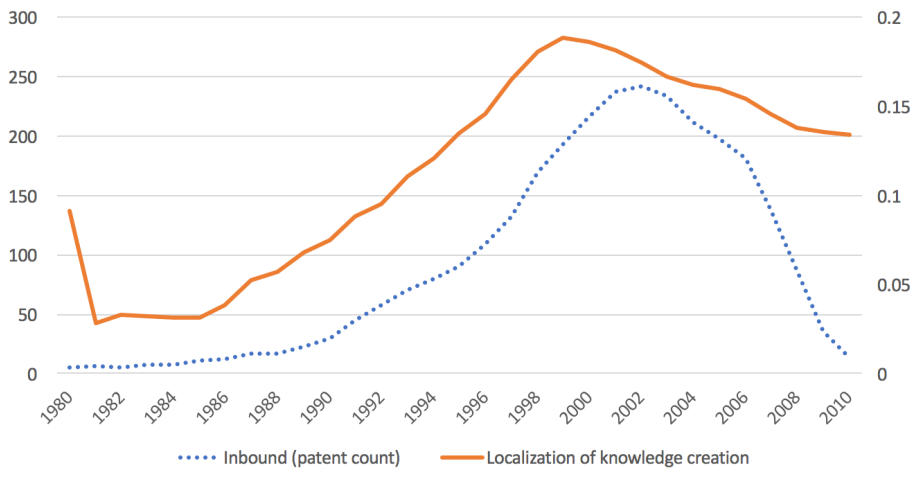


**Figure 24. Localization of knowledge creation, inbound R&D and outbound R&D in Taiwan, 1980-2010**




## 2.d. Localization of knowledge creation and Outbound R&D

Lastly, Figures 21 and 22 show that there is a similar increasing trend for localization variable and outbound R&D. That is, as the firms increasingly use patents from the same country, they build more capabilities to pursue R&D activities abroad. This confirms the argument of Lee and Lee (1992) and the IDP theory that growth in the national innovation system (R&D capabilities of firms) facilitated the capability of local firms to pursue R&D activities abroad (i.e., the shift or the growth in the NIS variables in Korea and Taiwan helped predict their growth in outbound R&D).

# VI. Conclusions and Recommendations

The results presented in parts 1 and 2 of this study answer the research questions. The first research question asked *do the trends between inbound and outbound R&D reflect the FDI flows in China, Korea and Taiwan?* The graphical trend analysis shows that inbound and outbound R&D flows in Korea, Taiwan and China reflect their respective FDI flows. Specifically, the trend of initially higher rate of inbound R&D, that converges with outbound R&D and finally with higher outbound R&D rates can be observed in the cases of the successful catching up countries, particularly in Korea and Taiwan. This matches with the predictions of the investment development path (IDP) model, which argues that the flow of investment is a function of the economic stages of the countries. Specifically, in the earlier stages of economic growth, inflow of investments tends to grow faster than outflow of investments. This is followed by a convergence of the two flows, where the growth rate of FDI inflow weakens and FDI outflow begins to grow faster. Finally, in the later stages of growth, FDI outflow overtakes FDI inflow. The same pattern can be observed with the inbound R&D and outbound R&D shares of Korea and Taiwan. While China exhibits a pattern similar to that of other developing countries. That is, China still has relatively higher rate of inbound R&D than

outbound R&D. As such, China, until 2010, is still at the early stages of development.

The second research questions asked *how does inbound R&D relate with the NIS variables in Korea and Taiwan?* Inbound R&D does not have a long run relationship with locally assigned patents, nor does it influence the cycle time of technologies, and the diversification of technological classes. This result confirms the argument in Lee (2013) that transition from long cycle to short cycle time technology sectors does not occur automatically even with openness to FDI; rather it is a deliberate action by NIS actors. However, the regression results confirm that inbound R&D only has a long run relationship with the localization of knowledge creation. Specifically, the declining trend of inbound R&D is simultaneous with the increase in the localization variable. In other words, a decrease in the dependence in foreign ownership of locally invented patents increases the chances of patents citing older patents owned by other Korean or Taiwanese companies. It should be taken into consideration, however, that the amount of foreign-owned patents invented in Korea did not decline. That is, the patent count of inbound R&D has been increasing, however local ownership of patents invented locally increased at a much faster rate. This accounts for the decreasing trend of SHIA, or the share of patents with foreign assignees and local inventors, out of the total number of patents invented inside Korea and Taiwan. As such, while inbound R&D could still be welcomed, the

decline in the ratio or the dependence on foreign ownership of local R&D activities support the localization of knowledge creation.

The last research question was *how does outbound R&D relate with the NIS variables in Korea and Taiwan?* As presented in the previous chapter, three variables (except diversification) showed evidence of existing long run significant relationship with the outbound R&D, but more so significantly with the localization of knowledge creation. More specifically, the variable of localization of knowledge creation showed long-run relationship in both countries. This suggests that the growth in outbound R&D is supported by an improvement in the innovation capabilities of firms in Taiwan and Korea, as proxied by the NIS variables. This suggests that as the R&D capabilities of local firms get stronger, as reflected in the NIS variables, it can also be expected that these firms will pursue R&D overseas. This is not surprising, since access to foreign knowledge and technology through licensing agreements and technological imports will no longer be enough, as the incumbent firms would be less open to provide such access because the catching up firms start to be considered as their potential competitors. As such, local firms start to proactively access foreign bases of knowledge by engaging in R&D activities overseas.

For future research, other researchers should consider evaluating the impact of inbound and outbound R&D in countries in different stages of

development. Also to assess further the impact of outbound R&D to growth in the NIS and the productivity growth of the home country. As a policy implication, this study provides evidence that developing or catching up countries and firms should not merely rely on the R&D activities of foreign firms to improve their NIS. While R&D activities of foreign firms should be promoted and welcomed, the dependence or the ratio of foreign ownership of local R&D activities should be lessened by promoting growth of the R&D activities of local firms.

# VII. References


Alvstam, C., Dolles, H., and Ström, P. (2014). Asian Inward and Outward FDI: New Challenges in the Global Economy – An Introduction. In C. Alvstam, H. Dolles, and P. Ström (Eds.), *Asian Inward and Outward FDI: New Challenges in the Global Economy*, (1-16). New York: Palgrave Macmillan.

Aw, B. Y. (2003). Technology acquisition and development in Taiwan. In S. Lall and S. Urata (Eds.), *Competitiveness, FDI and Technological Activity in East Asia* (168-190). Massachusetts: Edward Elgar Publishing, Inc.

Branstetter, L. G. (2004). Do stronger patents induce more local innovation? *Journal of International Economic Law*, 7(2), 359–370. https://doi.org/10.1093/jiel/7.2.359.

Chan, V. (2000). Foreign Direct Investment and Economic Growth in Taiwan's Manufacturing Industries. In T. Ito and A. Krueger (Eds.), *The Role of Foreign Direct Investment in East Asian Economic Development, NBER-EASE Volume 9*, (349-366). Chicago: University of Chicago.

Chen, C.-M., Melachroinos, K.A., Chang, K.T., (2010). FDI and local economic development: the case of Taiwanese Investment in Kunshan. *European Planning Studies 18 (2*), 213–238.

Chen, T., and Chen, Y., (1995). Foreign Direct Investment, *Journal of Industry Studies*, 2(1), 57-68, DOI: 10.1080/13662719500000004

Cheng, L. K., and Ma, Z. (2010). China's outward foreign direct investment. In R. C. Feenstra and S. J. Wei (Eds.), *China's Growing Roles in World Trade (Chapter 14),* (545-578). Chicago University of Chicago Press.

Choi, Y. S. and Kim, K. W. (2011). What Explains Firms' Innovativeness in Korean Manufacturing? Global Activity and Knowledge Sources. In Hahn, C. H. and Narjoki, D. (Eds.), *Globalization and Innovation in East Asia.* Jakarta: ERIA.

Dachs, B. & Pyka, A. (2010). What drives the internationalisation of innovation? Evidence from European patent data, *Economics of Innovation and New Technology*, 19(1), 71-86, DOI: 10.1080/10438590903016476

Dunning, J. and Narula, R. (1994). Transpacific foreign direct investment and the investment development path: the record assessed. *Essays in International Business*, 10, pp. 1-69.

Dunning, J., (1994). Re-evaluating the benefit of foreign direct investment. In UNCTAD Transnational Corporations, 3(1) pp. 23–51.

Erdal, L. and Gocer, I. (2015). The Effects of Foreign Direct Investment on R&D and Innovations: Panel Data Analysis for Developing Asian Countries. *Procedia - Social and Behavioral Sciences*, 195, pp. 749– 758.

European Institute for Asian Studies (EIAS) (2014). Taiwan's outward foreign direct investment (OFDI) into the European Union and its member states. Brussels: EIAS.

Guellec, D. and Van Pottelsberghe, B. (2001). The internationalization of technology analysed with patent data. *Research Policy (30),* pp. 1253-1266.

Guloglu, B., & Tekin, R. Baris. (2012). A panel causality analysis of the relationship among research and development, innovation, and economic growth in high-income OECD countries. *Eurasia Economic Review, 2(1),* 32-47.

Günther, J. and Gebhardt, O. (2005). Eastern Germany in the Process of Catching Up: The Role of Foreign and West German investors in Technological Renewal, *Eastern European Economics*, 43(3), pp. 78-102.

Hahn, C. H. and Narjoko, D. (2011). 'Globalization and Innovation in East Asia', in Hahn, C. H. and Narjoki, D. (eds.), *Globalization and Innovation in East Asia.* ERIA Research Project Report 2010-04, pp. 1-19. Jakarta: ERIA.

Jafffe, A. and Trajtenberg, M. (2002). Introduction in *Patents, Citations and Innovations: A window on the knowledge economy* (1-22). Massachusetts: MIT.

Kafouros, M., Buckley P., Sharp, J., and Wang, C. (2008), "The Role of Internationalization in Explaining Innovation Performance," *Technovation*, 28 (1–2), 63–74. https://doi.org/10.1016/j.technovation.2007.07.009

Kim, L. (2003). The dynamics of technology development: lessons from the Korean experience. In S. Lall and S. Urata (Eds.), *Competitiveness, FDI and Technological Activity in East Asia* (168-190). Massachusetts: Edward Elgar Publishing, Inc.

Kim, June-Dong and Sang-In Hwang (2000), 'The Role of Foreign Direct Investment in Korea's Development: Productivity Effects and Implications for the Currency Crisis'. In T. Ito and A. O. Krueger (eds), *The Role of Foreign Direct Investment in East Asian Economic Development* (267-294), Chicago: University of Chicago Press.

Kogut, B. and Chang, S. J. (1991). Technological capabilities and Japanese Foreign Direct

Investment in the United States. *The Review of Economics and Statistics*, 73(3), pp. 401-413.

Kolstad, I. and Wiig, A., (2012). What determines Chinese outward FDI? *Journal of World Business 47,* 26-34.

Kwon, S. K., Park, H. W., So, M., & Leydesdorff, L. (2012). Has globalization strengthened South Korea's national research system? National and International Dynamics of the Triple Helix of scientific co-authorship relationships in South Korea. *Scientometrics* (90), pp. 163-176.

Lee, C. and Lee, K. (1992). A transition economy and outward direct foreign investment: the case of South Korea. *Seoul Journal of Economics,* 5(1), pp. 89-111.

Lee, J. W. (2006). *Globalization of R&D – How to measure?* [Powerpoint slides]. Retrieved from http://ieeexplore.ieee.org/document/4077381.

Lee, K. (2013). *Schumpeterian Analysis of Economic Catch-up: Knowledge, Path Creation, and the Middle-income Trap.* Cambridge: Cambridge University Press.

Lee, K., Kim, M. & Kwak, J. (2012). "Places for Korean firms in China: looking for a viable international division of labor in 1990–2010." *Journal of the Asia Pacific Economy, 17(1),* 4-21.

Lee, K. and Plummer, M. (1992). Competitive Advantages, Two-Way Foreign Direct Investment, and Capital Accumulation in Korea. *Asian Economic Journal*, 6(2), pp. 93-113.

Lee, K. & Wang, (2010). "Science and Technology Institutions and Performance in China: The Semi-Conductor Industry," in *Institutional Dynamics of China's Great Transformation*, Huang, Xiaoming (Ed.) Routledge.

Lee, K. & Yoon, M. (2010). International, Intra-national, and Inter-firm Knowledge Diffusion and Technological Catch-up: The US, Japan, Korea, and Taiwan in the Semiconductor Industry",

Lee, K. & Kim, Y.K. (2016). Intellectual property rights and technological catch-up in Korea. In *Economic Catch-up and Technological Leapfrogging,* Massachusetts: Edward Elgar Publishing, Inc., pp. 56-85.

Lemoine, F. (2000). *FDI and the Opening Up of China's Economy*. Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). Paris.

Maskus, K., & Penubarti, M. (1995). How trade-related are intellectual property rights? *Journal of International Economics*, 39(3–4), 227–248. https://doi.org/10.1016/0022-1996(95)01377-8.

Narula, R. & Dunning, J. (2010). Multinational Enterprises, Development and Globalization: Some Clarifications and a Research Agenda. *Oxford Development Studies*, 38(3), pp. 263-287.

Park, H. W. & Leydesdorff, L. (2008). Korean journals in the Science Citation Index: What do they reveal about the intellectual structure of S&T in Korea? *Scientometrics 75(3),* pp. 439-462.

Park, S. C., Alvstam, C., Dolles, H., and Ström, P. (2014). Samsung Electronics: From 'National Champion' to 'Global Leader'. In C. Alvstam, H. Dolles, and P. Ström (Eds.), *Asian Inward and Outward FDI: New Challenges in the Global Economy*, (179-200). New York: Palgrave Macmillan.

Shapira, P., Youtie, J., Kay, L. (2011). National innovation systems and the globalization of nanotechnology innovation. *The Journal of Technology Transfer*, 36(6), pp. 587-604. https://doi.org/10.1007/s1096 1-011-9212-0.

van Pottelsberghe, B. and Lichtenberg, F. (2001). Does Foreign Direct Investment Transfer Technology across Borders? *The Review of Economics and Statistics*, 83(3), pp. 490-497.

Thurbon, E. and Weiss, L. (2006). Investing in Openness: The Evolution of FDI Strategy in South Korea and Taiwan, *New Political Economy*, 11(1), pp. 1-22.
Thorbecke, W. and Salike, N. (2013). "Foreign Direct Investment in East Asia," Policy Discussion Papers 13003, Research Institute of Economy, Trade and Industry (RIETI).

Willoughby, K. (2018). Endogenous innovation, outward-bound international patenting and international economic development. *The Journal of Technology Transfer*.

Wu, H. L., Chiu, Y. C., & Lee, T. L. (2010). IPR and Catchup: The Case of Taiwan's IC Industry, Chapter 6 in *Intellectual Property Rights, Development, and Catch-Up: An International Comparative Study*, H. Odagiri, A. Goto, A. Sunami & R. Nelson (Eds.), pp. 168-207. Oxford: Oxford University Press.

Yang, C., & Kuo, N. (2008). Trade-related influences, foreign intellectual property rights and outbound international patenting. *Research Policy*, 37(3), 446–459. https://doi.org/10.1016/j.respo l.2007.11.008.

Zucker, L. and Darby, M. (2008). Categorizing Science and Technology across Articles, Patents, Doctoral Programs and Industries, Doctoral Programs, and Industries , " machine - readable concordance at Nanobank.org, p osted March 3, 2008 , at http://www.nanobank.org/downloads.php under "Documentation for Zucker - Darby Science Area Categorizations." Also available at the the Social Science Research Network (SSRN) at http://ssrn.com/abstract=1109109.

Zivot, E., & Wang, J. (2007). *Modeling financial time series with S-Plus®* (Vol. 191). *Cointegration* (pp. 431-480). Springer Science & Business Media.

# VIII. Abstract (in Korean)

본 연구는 동아시아 (한국, 대만, 중국) 연구 개발의 세계화 추세와 COMETS 2.0 의 기업 특허 데이터를 이용하여 1980 년부터 2010 년까지 NIS (National Innovation Systems)를 통해 역학 관계를 분석 하였다. R & D 의 세계화는 인바운드 R & D 와 아웃 바운드 R & D 로 구성된다. 인바운드 R & D 는 외국 기업이 소유 한 국경 내에 연구 활동 및 시설이 있음을 나타낸다. 반면, 아웃바운드 R&D 는 국내 기업이 해외 현지에서 수행한 연구활동을 일컫는다. 이 연구는 NIS 개발에 대한 R & D 의 세계화의 영향에 초점을 맞춰 특허 데이터를 사용하여 인바운드 및 아웃 바운드 R & D 를 측정한다. 즉, 인바운드 R & D 는 외국 출원인이 소유하고 있지만 국내에서 발명 된 특허에 의해 측정되는 반면 아웃 바운드 R & D 는 국내 출원인이 소유하고 해외에서 발명 된 특허로 측정된다.

본 연구는 두 부분으로 구성되어 있다. 첫 번째는, 인바운드와 아웃 바운드 R & D 의 추세는 중국, 한국 및 대만의 FDI 추세를 반영하는가에 관한 것이고 이 결과는 각국의 FDI 추세와 유사 함을 보여준다. 투자 개발 경로 (Investment Development Path) 이론에 따르면 한국과 대만의 성공적인 추격경제 (catch-up economies) 국가는 경제가 발달함에 따라 인바운드 R & D 와 아웃 바운드 R & D 를 융합하였다. 특히 인바운드 R & D 는 성장의 초기 단계에서 먼저 시행하였고 경제 성장의 후기 단계에서는 아웃 바운드 R & D 가 더 빠른 속도로 성장했고 이를 인바운드 R & D 추세를 뛰어넘었다.

이 논문의 두 번째 부분은 인바운드 R & D 와 아웃바운드 R&D 가 한국과 대만의 NIS 변수와 각각 어떤 관계를 보이는지에 관한 내용이다. 실증분석은 변수들의 stationarity 특성을 따라 VAR, VECM, 그리고 ARDL 모델을 사용하였다. 분석 결과, 다음과 같은 장기적인 관계를 보인다. (1) 인바운드 R&D 를 통해 지식의 현지회 가치를 예측하는 데에 도움을 주고, (2) 지식의 현지화는 국내 기업이 등록한 특허의 수에 영향을 주고, (3) 지식의 현지화는 아웃바운드 R&D 에 영향을 준다.

**주요어**: R & D 의 글로벌화, 인바운드 R & D, 아웃 바운드 R & D, 국가 혁신 시스템 (NIS), VAR, VECM, ARDL
**학번**: 2016-24529