ERIA-DP-2018-10

ERIA Discussion Paper Series

Innovation Process in Public Research Institute: Case Studies of AIST, Fraunhofer, and ITRI*

Byeongwoo KANG†

Institute of Innovation Research, Hitotsubashi University

March 2019

Abstract: *The design of national innovation systems has attracted attention from scholars and policymakers. Firms, universities, and government organisations (including public research institutes) are defined as the three major players, and interactions between the players are considered the key to a successful national innovation system. However, public research institutes are relatively understudied compared to firms and universities, even though their contribution to national innovation is not trivial. This paper aims to understand the detailed processes and reveals practical information regarding the innovation process in public research institutes. Focusing on the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, Fraunhofer-Gesellschaft (Fraunhofer) in Germany, and the Industrial Technology Research Institute (ITRI) in Taiwan, this paper analyses and compares innovation processes of public research institutes with their patent data. Based on findings, this study further discusses issues for better management of public research institutes.*

Keywords: innovation, national innovation system, patent data, public research institute
JEL Classification: O25

* The author would like to thank two anonymous reviewers for their comments. All remaining errors are the author's own.
† Correspondence author at: byeongwoo.kang@iir.hit-u.ac.jp

1. Introduction

Innovation is the creation of new value from new ideas using new methods. It is the engine of economic growth. How to design systems to derive innovation at the national level – that is, national innovation systems (NIS) – has been an important issue for scholars and policymakers (see e.g. Freeman, 1987; Nelson, 1993). Firms, universities, and government organisations (including public research institutes) are defined as the three major NIS players, and interactions between the players are considered the key. Their interactions create new value by combining new knowledge and resources as well as combining conventional knowledge and resources in new ways. For example, when companies collaborate with universities to develop new technology, their collaboration leads to knowledge exchange between the firms and universities.

Substantial literature focusing on NIS exists. The Organisation for Economic Co-operation and Development (OECD) published a key report in 1999, and research on NIS flourished thereafter. Most studies regarding NIS have focused on the collaboration between universities and firms – only two of the three main players. Public research institutes have received less attention despite their active involvement in innovation and, for some, key role in the development of industries. Some public research institutes have enormous budgets for conducting research and development (R&D), surpassing industry budgets. Other institutes play a key role in deciding the speed and direction of development of an industry by forming industrial consortia and fora.

This paper investigates how public research institutes contribute to innovation. It aims to understand the role of the public research institute in NIS, looking at the detailed processes rather than testing hypotheses. This paper focuses on three case studies to illuminate innovation processes in three institutes: the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, Fraunhofer-Gesellschaft (Fraunhofer) in Germany, and the Industrial Technology Research Institute (ITRI) in Taiwan. They were chosen because they are often considered as amongst the key public research institutes of their respective countries and as such have garnered attention in the extant literature (Freeman, 1987; Tanaka, 1989; Chen and Sewell, 1996; Beise and Stahl, 1999; Yang et al., 2009; Wong et al., 2015). In addition, as will be seen later, AIST, Fraunhofer, and ITRI focus on similar research fields and show high correlations in their technological portfolios.

This study contributes to the literature by adding a missing component that was overlooked by previous studies. It focuses on the mission of public research institutes to conduct R&D. As will be reviewed in the next section, prior studies discussing public research institutes have several limitations, such as confusing them with universities despite their differences and neglecting the evolving roles of public research institutes with changes in surrounding conditions.

The remainder of this paper is organised as follows. Section 2 reviews relevant theories from prior studies in order to define and position this study. Section 3 describes how data were collected and analysed. Section 4 presents findings, and section 5 discusses these findings along with policy implications. Finally, section 6 concludes.

2. Literature Review

This section reviews some of the prior studies relevant to the current study. By doing so, this section aims to show the limitations of the existing research and define the position of the current study.

2.1. Linkages in national innovation systems

Freeman (1987) proposed the NIS concept based on a case study of Japan in the 1980s. He recognised the R&D consortia in Japan and collaborative relationships of government organisations as a national system, arguing that other developed countries could harness such a system for benefits at the same level. This was followed by international comparative research regarding NIS conducted by a group led by Professor Richard Nelson (1993) at Columbia University. The OECD (1999) took over the project and proposed an innovation policy to its member countries based on the outcomes of its qualitative and quantitative research (OECD, 1999).

As the backgrounds of each country are different and heterogeneous in various important respects, the application of the NIS concept in practice varies between countries. For example, Bernardes and Albuquerque (2003) and Ribeiro et al. (2006) have indicated that the NIS in developed countries operates a different mechanism from developing countries.

However, despite such differences, prior studies commonly define firms, universities, and governments (including public research institutes) as NIS players. The key to NIS is the linkages between firms, universities, and public research institutes. There are differences in knowledge and capabilities across the players. The NIS concept posits that innovation can be achieved via the exchange of knowledge and capabilities between the players. Accordingly, NIS studies consider that although the ultimate role of innovation lies with firms, research outputs from universities and public research institutes contribute to the innovation by firms. Such a tendency is strong especially in high-tech industries such as bioengineering.

However, of the three possible types of linkages, most prior studies have discussed the linkage between universities and firms (e.g. Perkmann et al., 2013). Public research institutes have garnered less attention. In addition, prior studies often have conflated universities and public research institutes, just because both are publicly funded (Roessner, 1993; Beise and Stahl, 1999; Diez, 2000; van Beers et al., 2008).

This paper, however, separates them for the following three reasons. First, public research institute consume all resources for research. While universities also consume a large share of their resources for research, substantial resources are allocated for education as well. Second, research output quality differs between public research institutes and universities. Although many research projects are run in universities, most of them are carried out by students, especially doctoral students, whose time is mostly spent on learning (Behrens and Gray, 2001). Student researchers in universities are expected to achieve successful research outcomes, but their primary interest is to obtain academic degrees through learning and research experience. Meanwhile, most researchers in public research institutes have finished their graduate courses and are expected to deliver appropriate research outputs. Third, the pattern of knowledge flows through the mobility of researchers is different between universities and public research institutes. The majority of student researchers leave their universities after obtaining their degrees. Researchers at public research institutes are also mobile, but to a lesser extent than student researchers. Accordingly, tacit knowledge such as know-how is likely to remain and accrue in public research institutes to a greater extent compared to universities. In sum, differences in expected missions, capability of researchers, and knowledge flows and accrual suggest differences in innovation processes between universities and public research institutes.

2.2. The role of public research institutes

2.2.1. As a catch-up catalyst

Public research institutes aimed at R&D have been contributing to national innovation by upgrading national technological capacity. In the case of the Republic of Korea, the Electronics and Telecommunications Research Institute (ETRI) played a critical role in the country's catch-up (Chung and Lee, 1999; Mock, 2005; Yoo et al., 2005). Collaborating with Qualcomm, which was trying to commercialise its CDMA technology, ETRI contributed to commercialisation and authorisation of IS–95, which was the first CDMA-based standard in the mobile communications industry. During the collaboration with Qualcomm, ETRI acted as a project manager to domestic firms. Similar cases can also be found in other Korean industries (Kim, 1997; Kim and Lee, 2015). The contributions of public research institutes in terms of catch-up can also be found in Taiwan and Thailand (Mazzoleni and Nelson, 2007; Intarakumnerd and Chairatana, 2008). Even in Japan, the effort of the Agency of Industrial Science and Technology (the predecessor of AIST) was considered one of the determinants that enabled the Japanese semiconductor industry to catch up to the Western level (Freeman, 1987).

However, the role of public research institutes after catch up is not well understood. As technological capability in emerging countries converges towards the level of that in advanced countries, the role of public research institutes in catching up diminishes. Further, the new role after catch up remains under-discussed. One new role is to bridge between universities' basic research and firms' commercialisation of that basic research (Cohen et al., 2002). As the speed of technological advancement accelerates and technologies in products and services become more complex, firms are expected to employ open innovation. Although some new roles have been proposed, information overall is lacking in this respect.

2.2.2. As an innovation seed provider

Consistently through time, public research institutes, whose primary role is R&D, have played a key role by providing innovation seeds. However, such a role has been questioned recently. Historically, public research institutes have indeed provided innovation seeds that later changed the world completely. In particular, public research institutes whose mission was to conduct defence and space research receive substantial budgets for challenging and complex R&D activities, which present opportunities to find new knowledge, new applications, and, indeed, paradigm-shifting breakthroughs (Nelson, 1993; Mowery, 2010). For example, the Internet was invented in a research project by the Defense Advanced Research Projects Agency (DARPA), which played a pivotal role in the information revolution in the late 20th century (Mowery and Simcoe, 2002). In addition, substantive knowledge garnered via military robotics research is applied in commercial robotics contexts.

Importantly, the current innovation model is not supporting these types of possibilities. In the past, innovation has been considered a linear process (Kline, 1985). That is, innovation occurs in one direction: research, then development, then production, and finally marketing. However, scholars recognised that there is a gap between the linear model and reality. Bearing in mind the complexities inherent in actual, empirical contexts, the innovation process model was further developed as a chain model. The chain model is different from the linear model in several ways. First, the chain model recognises that there are several paths in the innovation process. In contrast, the linear model has only one path, from research to marketing. Second, as shown in the chain model, there exist feedback mechanisms between organisations, and the feedback is then reflected in the innovation process. Third, research is not the first step in the chain model. Rather, research is conducted in each step based on necessity. The innovation process that begins from research is also known as the 'technology push' model. Even if the technology push model explains *some* innovations, the 'demand pull' model explains *most.* Lastly, knowledge accrues as shown in the chain model; this is different from the linear model where new knowledge is always employed.

2.3. Conceptual framework: factors that affect the performance of public research institutes

As apparent from the literature review, public research institutes have been assigned various roles for a number of different purposes. Several factors are necessary for them to successfully achieve their assigned roles (Intarakumnerd and Goto, 2016). The availability of such factors tends to influence their success and failure.

The first and most important factor is funding. For example, Fraunhofer receives about a third of its total budget from the government and the remainder from the industry and other revenue sources. Conversely, ITRI receives 65% of its revenue from the government and 35% from the industry, and AIST receives almost its entire total budget from the government. These differences affect the institutes' R&D choices.

The second factor is researchers. This is largely influenced by the funding structure. When public research institutes receive stable government block funding, they can hire permanent researchers. An example is AIST. In this situation, the researchers' knowledge remains within the institute, and knowledge accumulation occurs easily. In the absence of such funding, the institutes can only hire fixed-term researchers, as occurs at Fraunhofer and ITRI. In such cases, it is difficult for knowledge to accrue within the organisations.

The third factor is the research agenda. This is also largely influenced by the funding structure. For example, whether the funding comes from the industry or from the government is a critical concern for public research institutes. When they rely heavily on government block funding, it is possible to set a basic research agenda with long-term objectives, although their research agenda must be in the national interest. Meanwhile, if public research institutes rely on industry funding rather than government funding, they must have a commercially oriented research agenda in order to meet their funders' expectations.

The fourth factor is performance evaluation. Various indicators have been applied to assess the performance of public research institutes such as patents, publications, technology transfers, spin-offs, R&D contract volume, and budget size. However, as the economic outcomes of public research institutes are still difficult to measure, despite these various indicators, measurement of performance remains a concern amongst policymakers.

The fifth factor is the location of public research institutes. Geographical proximity is important for knowledge transfer and innovation because it increases interactions between researchers from different organisations and the ability to share facilities.

The final factor is governance. This is important to set the overall strategic direction of public research institutes. For example, in order to increase inputs from and interactions with the industry, chief executives are recruited from the industry. Institutes such as AIST and ITRI are some of the examples.

3. Data

3.1. AIST, Fraunhofer, and ITRI

This subsection briefly describes the three public research institutes of interest. All the descriptions in this subsection draw on the webpages and recent annual reports of the three organisations.

This study focuses on AIST, Fraunhofer, and ITRI, amongst others, for several reasons. First, as mentioned in Section 1, these institutes are acknowledged in the literature. Second, they focus on common research fields such as information and communications technology (ICT), material science, life science, and energy. As will be seen in section 4.1, they show high correlations in their technological portfolios. Third, they have a large amount of patent data available to conduct patent data analysis. For such reasons, I did not include other public research institutions in other countries, for example the National Institute of Standards and Technology (NIST) in the United States or the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (Intarakumnerd and Goto, 2016). These were not chosen for the current study either because the focus of their research/mission was different or their patent data were insufficient – as was the case for NIST. The institute's core competencies are in measurement science, rigorous traceability, and the development and use of standards, where patenting is rare. Additionally, CSIRO has few United States patent applications from which to obtain reliable results.

3.1.1. AIST

AIST is one of the largest public research institutes in Japan. It focuses on bridging innovative technologies between basic research and commercialisation. It consists of 42 organisations (as of 2014) classified into seven fields: energy and environment, life science and biotechnology, information technology and human factors, materials and chemistry, electronics and manufacturing, geological surveys, and national metrology.

AIST employs 2,300 researchers, with an additional 4,800 visiting researchers from academia and industry. The annual revenue is circa 100 billion yen, around 75% of which consists of subsidies, commissioned research funds, and grants from the government.

3.1.2. Fraunhofer

Fraunhofer is Europe's largest application-oriented research institute. It conducts R&D with others to transform original ideas into innovations that benefit society and strengthen both the German and the European economy. Fraunhofer is specialised in the following seven fields: defence and security, ICT, life science, light and surfaces, materials and components, microelectronics, and production.

As of 2014, Fraunhofer consists of 66 research institutes and research units within Germany with a workforce of 24,000 employees. The annual budget is around 2.1 billion euros, more than 1.7 billion euros of which is from contracted research projects. Defence research provides an important source of income. More than 70% of the contracted research projects are collaborations with the private sector, or publicly funded commissioned research projects; the remainder depend on public funds from governments.

3.1.3. ITRI

ITRI is a Taiwan-based non-profit-making R&D organisation engaging in applied research and technical services. ITRI has been dedicated to helping industries stay competitive and sustainable. ITRI integrates its six major research areas: biomedical technology and device, green energy and environment, material and chemical, mechanical and systems, information and communications, and electronics and optoelectronics. These areas are defined in three application domains: Smart Living, Quality Health, and Sustainable Environment.

As of 2014, ITRI has 15 R&D units and 10 service units, with 5,800 employees. The annual budget is 20 billion New Taiwan dollars, about half of which derives from competitively won funds from the government and the other half from contract research projects, service provision, and technology transfer.

3.2. Patent data

Thanks to the rapid advancement of information technology and digitalisation in recent decades, data are readily amenable to digitisation and storage in databases. In addition, because of the development of computers and software, processing large amounts of data has become easy. As a result, patent data have been used in various academic fields and innovation research is one such field which frequently uses patent data. The patent system grants exclusive ownership over inventions for a certain period of time in the content of inventions which are publicly disclosed and claimed. Accordingly, patent data provide information not only about innovation output but also innovation processes (Jaffe and Trajtenberg, 2002). Concretely, information about people involved (applicants and inventors), timing (filing dates), regions (patent offices, and addresses of applicants and inventors), technological knowledge (inventions and citations), and so on can be retrieved (Kang, 2015; Kang and Tarasconi, 2016). Patent statistics are based on these kinds of information and used in many empirical studies. Patent data analysis has several merits. First, it can remove the biases inherent in subjective survey- and interview-based methods. Second, effort and cost are lower in terms of collating patent data thanks to well-designed databases.

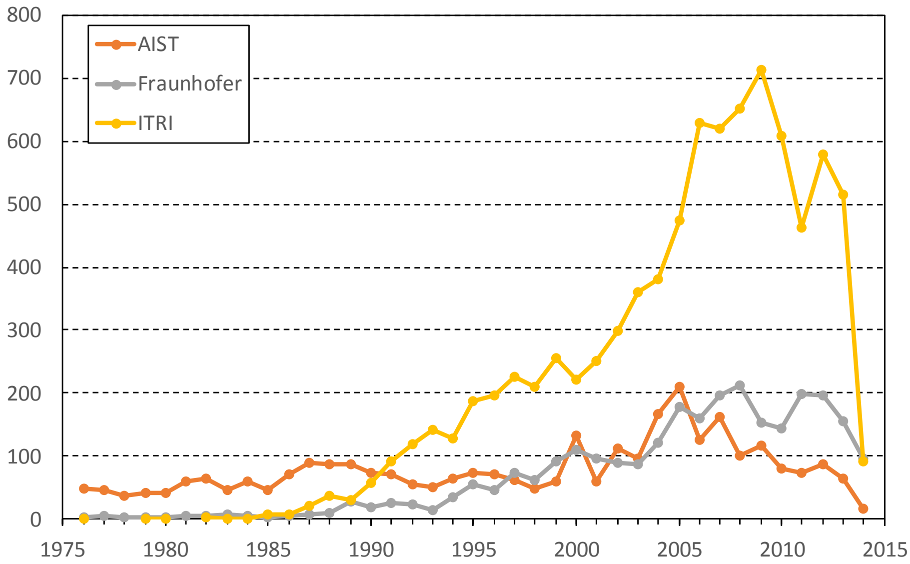
This paper employs patent statistics (Griliches, 1990; Jaffe and Trajtenberg, 2002) to observe innovation processes of public research institutes. This study employs patent data held by the United States Patent and Trademark Office (USPTO) for three reasons (Nagaoka et al., 2010). The first reason is to minimise 'home office' bias. When a firm files a patent, it tends to file first in the patent office of its own territory. Since this study focuses on AIST, Fraunhofer, and ITRI, there are patent filing biases in Japan, Germany, and Taiwan. As a result, the three public research institutes cannot be compared in a fair manner. However, the US market is often considered the primary country market after their own for many organisations. Therefore, many firms file patents with USPTO after their home offices. Accordingly, using USPTO patent data helps minimise home office biases. The second reason to employ USPTO patent data concerns the availability of citation data. Since patent citations are used for examining patent applications, applicants have no incentive to add citations. However, in order to file patents with USPTO, one must provide all the information on which the patent application is based (duty of candour). Patent applications that fail to do so will be rejected. As a result, USPTO patent data tends to provide more citation data than other patent offices (Layne-Farrar, 2011). The third reason is to minimise 'home citation' biases. Patent citations are likely to come from information near the applicants and inventors (Michel and Bettels, 2001). Therefore, it is assumed that AIST, Fraunhofer, and ITRI are responsible for significant citations of patents that are close to them in spatial terms. Using USPTO patent data may militate against home citation biases. One problem with this method is that there might exist a US citation bias, in which a disproportionate number of citations of a patent application come from near the patent examiners. However, since this would evenly affect the three public research institutes, a fair comparison can be made between AIST, Fraunhofer, and ITRI.

4. Findings

4.1. Patent applications

Patent applications with USPTO by the three public research institutes are shown in Figure 1. AIST has been active in filing patent applications even before the formation of the institute in 2001. It has been filing patent applications with USPTO since 1975; these increased in the early 2000s before decreasing after 2005. Findings from the case of AIST imply that AIST considers USPTO to be an important target for patent applications. Meanwhile, Fraunhofer was filing patent applications to an extent less than or similar to AIST until 2005. An interesting fact here is that there were almost no patent applications filed by Fraunhofer with USPTO until the 1990s, but patent filing with USPTO has increased since then. This indicates that Fraunhofer started to focus on the US market in the 1990s. Finally, ITRI seems to have a great interest in the US market, more than AIST and Fraunhofer. Until 1985, patent applications with USPTO by ITRI were almost non-existent but have boomed since. Patent applications with USPTO by the three public research institutes decrease after 2010, but this is probably because the most recent data are not reflected in the database.

Figure 1. Patent Applications with USPTO



AIST = National Institute of Advanced Industrial Science and Technology (Japan), ITRI = Industrial Technology Research Institute (Taiwan), USPTO = United States Patent and Trademark Office.
Source: Author's calculations.

Next, the patent portfolio based on patent applications to USPTO is compared between the three public research institutes of interest. This analysis allows us to test if comparing AIST, Fraunhofer, and ITRI is valid. The patent portfolio of each institute was obtained by counting the number of patent applications per the technological classification known as the International Patent Classification. Then, the patent portfolio correlations between AIST, Fraunhofer, and ITRI were calculated. The results are displayed in Table 1. Since correlation levels are high, it is assumed that it is fair to compare the three institutes.

Table 1. Correlation of Patent Applications by AIST, Fraunhofer, and ITRI

	AIST	Fraunhofer	ITRI
AIST	1.000		
Fraunhofer	0.6882	1.000	
ITRI	0.7595	0.7427	1.000

AIST = National Institute of Advanced Industrial Science and Technology (Japan), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

4.2. Co-application analysis

This subsection analyses the co-application activities of AIST, Fraunhofer, and ITRI. Co-applicants are classified into seven types: 1) domestic firms, 2) foreign firms, 3) domestic universities, 4) foreign universities, 5) domestic research institutes, 6) foreign research institutes, and 7) individuals. The classification results are shown in Table 2 and Table 3.

Table 2. Co-applicants of AIST, Fraunhofer, and ITRI

	AIST	Fraunhofer	ITRI
No. of all co-applicants	464	186	152
No. of co-applicants: domestic firms	334 (72%)	83 (45%)	91 (60%)
No. of co-applicants: foreign firms	10 (2%)	58 (31%)	10 (7%)
No. of co-applicants: domestic universities	26 (6%)	24 (13%)	18 (12%)
No. of co-applicants: foreign universities	1 (0%)	10 (5%)	5 (3%)
No. of co-applicants: domestic public research institutes	23 (5%)	4 (2%)	3 (2%)
No. of co-applicants: foreign public research institutes	0 (0%)	5 (3%)	0 (0%)
No. of co-applicants: individuals	70 (15%)	2 (1%)	25 (16%)

AIST = National Institute of Advanced Industrial Science and Technology (Japan), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

Table 3. Co-applications of AIST, Fraunhofer, and ITRI

	AIST	Fraunhofer	ITRI
No. of all co-applications	996	375	622
No. of co- applications: domestic firms	758 (76%)	117 (31%)	462 (74%)
No. of co-applications: foreign firms	13 (1%)	127 (34%)	22 (4%)
No. of co-applications: domestic universities	71 (7%)	96 (26%)	101 (16%)
No. of co-applications: foreign universities	1 (0%)	21 (5%)	7 (1%)
No. of co-applications: domestic public research institutes	59 (6%)	6 (2%)	4 (1%)
No. of co-applications: foreign public research institutes	0 (0%)	6 (2%)	0 (0%)
No. of co-applications: individuals	94 (10%)	2 (1%)	26 (4%)

AIST = National Institute of Advanced Industrial Science and Technology (Japan), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

First, AIST filed a total of 996 patent applications with 464 organisations as co-applicants, mostly collaborating with domestic firms. The detailed breakdown is shown in Tables 2 and 3.

AIST’s case exhibits three differences from the cases of Fraunhofer and ITRI. First, the numbers of AIST’s co-applicants and co-applications are much greater than those of Fraunhofer and ITRI. Second, most of the co-applicants are domestic firms. These two findings indicate that AIST is active in collaborating with other organisations, but their focus is on domestic markets to a greater extent than Fraunhofer and ITRI. Third, collaboration with individuals is significant, rather than marginal. This result may reflect Japanese system protocols to use inventors’ names instead of applicants’ names. For example, before the Japanese Bayh–Dole Act, universities in Japan were banned from filing patent applications. Instead, inventors in universities used their own names as applicants instead of university names. Accordingly, it is assumed that most of the individuals denoted as AIST’s collaborators were probably in universities.

Fraunhofer filed a total of 375 patent applications with 186 organisations. Most collaborations were with domestic firms, but many also with foreign institutes and universities (Tables 2 and 3).

Fraunhofer’s case exhibits two differences from the cases of AIST and ITRI. First, Fraunhofer exhibits strong international presence, collaborating with various foreign organisations, which are not only firms but also universities. A lot of them were from European Union member states. Second, collaborations with universities (domestic and foreign universities) are substantial. The reason for this is not known, but some discussion is offered in the following section regarding this point.

Lastly, ITRI filed a total of 622 patent applications with 152 organisations. Most were with domestic firms, but many also with institutes and universities (Tables 2 and 3).

ITRI’s case is similar to that of AIST. That is, their primary collaborators are domestic firms. Although the number of individuals involved in collaborations is noteworthy, actual patent filings with individuals are rare. Meanwhile, universities seem to be important for ITRI as collaborators. Universities represent 12% of co-applicants, and the total number of co-applications with universities is large compared to AIST and Fraunhofer.

4.3. Patent citation analysis 1: geographical knowledge origin

Absorptive capacity is a firm's ability to recognise the value of new information, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990). Accordingly, absorptive capacity is considered a necessary ability to achieve innovation. This subsection shows how widely the three public research institutes of interest search knowledge for their R&D activity from patent data.

If a patent A cites a patent document B, we interpret this as knowledge flow occurring from patent document B to patent A. Based on addresses of applicants, national origins of the applicants are determined. Patent citations have been widely used as a proxy for knowledge flows (Fung and Chow, 2002; Jaffe and Trajtenberg, 2002; Nelson, 2009). Repetition of patent citation analyses, for example analysing citations of patent citations, allows the estimation of knowledge trajectories (Verspagen, 2007; Fontana et al., 2009; Martinelli, 2011).

Since patent citations are used for examining patent applications, it is the examiner who adds citations in the patent documents in principle. Patent examiners add citations to narrow the protection width claimed in patent applications and to reject patent applications. However, in reality, there is an incentive for applicants and inventors to add patent citations. For example, they add citations to help others understand claims and clarify inventions (Hedge and Sampat, 2008). In other words, adding patent citations can be considered an invention process. In addition, applicants must disclose all prior arts on which the proposed inventions are based. Hence, analysing patent citations allows us to understand the knowledge that influenced inventions.

Figure 2 indicates citations in patent applications by national origin, for AIST, Fraunhofer, and ITRI. The results are presented in 10-year steps from 1980 to 2010. The country-level reliance of R&D activity in AIST, Fraunhofer, and ITRI is illustrated. For example, AIST inventions in 1980 were based on the US (71%), Japan (17%), and Europe[1] (10%).

First, AIST relied significantly on US knowledge in 1980. It also relied more on the knowledge of domestic applicants than that of applicants from Europe. Overall, reliance on the US, Japan, and Europe amounts to 98% in total, which clearly indicates that knowledge was concentrated within the so-called triad (Europe, Japan, and US). However, with time, reliance on the knowledge of applicants from the US decreases, and AIST relies more on the knowledge of domestic applicants, particularly in 2010. That is, AIST has shifted its knowledge reliance from the US to Japan.

---

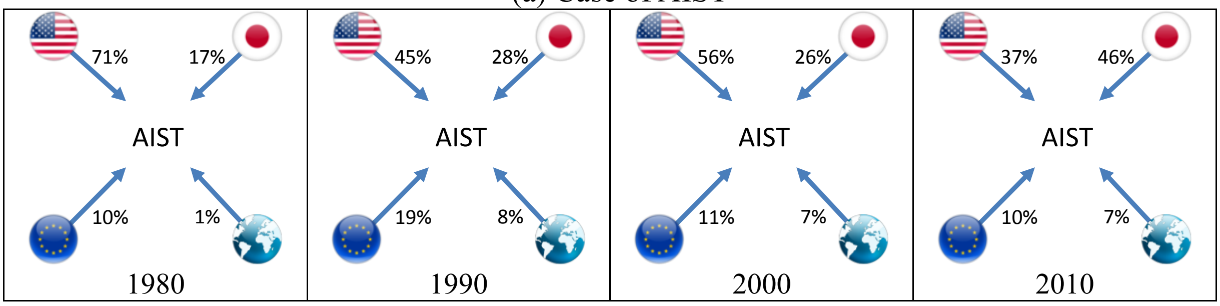
[1] Europe is defined in terms of the 28 European Union member states as of 2016.

Second, Fraunhofer only relied on the knowledge of applicants from Germany and Japan in 1980. Fraunhofer gradually starting filing with the USPTO from the late 1980s. By 1990, Fraunhofer was sourcing 43%, 49%, and 8% of its knowledge from applicants in the US, Europe, and Japan, respectively. Until 2010, Fraunhofer was sourcing 40% and 17% of its knowledge from the US and Japan, respectively. Reliance on the knowledge of applicants from Europe including Germany is seen to decrease whilst reliance on emerging economies such as the Republic of Korea and Taiwan increases. This indicates that the technological capabilities of the Republic of Korea and Taiwan are increasing in relative terms.

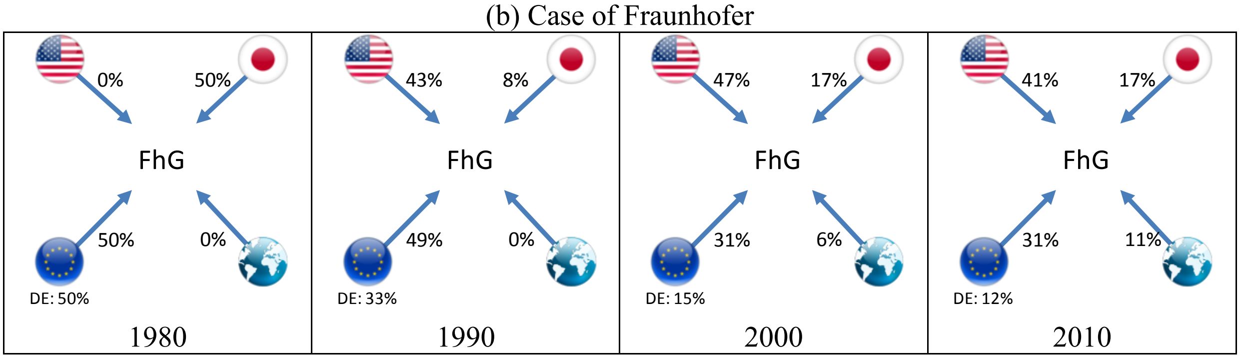
Finally, ITRI did not file patents with USPTO until 1980. In 1990 when ITRI filed a lot of patents with USPTO, ITRI sourced 46%, 16%, and 35% of its knowledge from applicants in the US, Europe, and Japan, respectively. Together this amounts to 97% of ITRI's knowledge reliance. Reliance on the knowledge of applicants from the US is around 50% in 2000 and 2010 whilst that from Europe is around 10%. Reliance on the knowledge of applicants from Japan decreases, measuring 19% in 2010, which is half of the value observed in 1990. Nevertheless, ITRI's reliance on knowledge from the US, Europe, and Japan is still high.

Figure 2. Changing Knowledge Origins in AIST, Fraunhofer, and ITRI

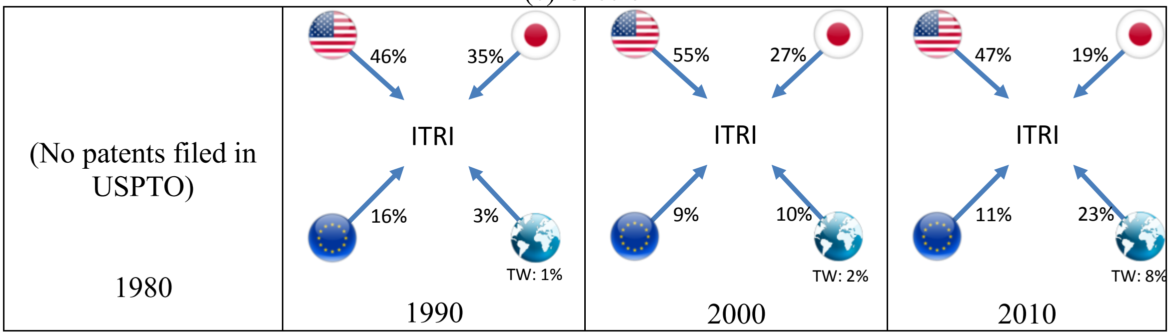
(a) Case of AIST



(b) Case of Fraunhofer



(c) Case of ITRI



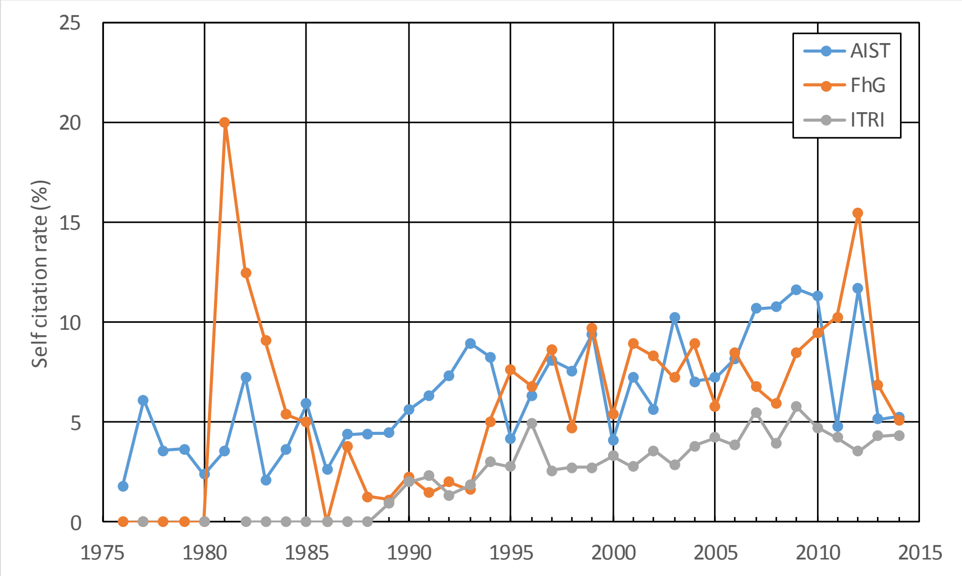
AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan), USPTO = United States Patent and Trademark Office.
Source: Author's calculations.

4.4. Patent citation analysis 2: knowledge accumulation

This subsection compares self-citation rates and analyses knowledge accumulation within AIST, Fraunhofer, and ITRI. Knowledge accumulation can be calculated by counting the number of times that an applicant cites their own patents. So, if knowledge accrues within an organisation significantly, the organisation tends to cite internal knowledge rather than external knowledge. As a result, self-citation increases with knowledge accumulation. In contrast, if knowledge does not accrue within an organisation, the organisation has a greater tendency to cite external knowledge. In this case, self-citation rates do not increase, and may remain zero or very low.

The results are shown in Figure 3. The horizontal axis is the application year and the vertical axis is the rate of self-citation. Until 1985, Fraunhofer, had high trend variability because the number of patent applications was small and the trends are influenced by small changes. However, with time, this diminishes. There are two key findings in this figure. First, there is some evidence to suggest that the share of the three institutes' self-citations increases over time. This indicates increasing knowledge accumulation within each; hence, they rely on internal knowledge more than external knowledge. Second, AIST's and Fraunhofer's self-citation rates are higher than that of ITRI. In the analysis above, ITRI filed the largest number of patent applications with USPTO compared to AIST and Fraunhofer; this is clearly not synonymous with knowledge accrual within the organisation.

Figure 3. Self-citation Rates



AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

4.5. Patent citation analysis 3: knowledge spillover

The current subsection analyses the extent to which inventions by AIST, Fraunhofer, and ITRI affected subsequent inventions by others. That is, knowledge spillover to others. Accordingly, this subsection calculates how many times patents are cited by others (non-self-citation). The analysis is twofold: knowledge spillover to domestic applicants and that to foreign applicants.

4.5.1. Knowledge spillover to domestic applicants

The first analysis focuses on knowledge spillover to domestic applicants, i.e. AIST's knowledge spillover to applicants in Japan, Fraunhofer's knowledge spillover to applicants in Germany, and ITRI's knowledge spillover to applicants in Taiwan.

The results are shown in Figure 4, which illustrates the number of patent applications from Japan, Germany, and Taiwan that cite the three institutes' patents respectively. For example, in 1995, about 210 patent applications from Japanese applicants cited AIST's patents, about 50 from German applicants cited Fraunhofer's patents, and about 50 also from Taiwanese applicants cited ITRI's patents.

It is readily observed that the number of patent applications that cite either of the three institutes' patents increases as time goes on. This implies that the influence of AIST, Fraunhofer, and ITRI on domestic applicants is increasing. However, after around 2004, the trends associated with AIST and Fraunhofer either decrease of stay constant, whilst ITRI trends upwards significantly. This may indicate that ITRI's importance to domestic applicants is increasing. In addition, after 2010, all trends exhibit sharp, dramatic decreases. We speculate that this is a function of a database time lag: it takes time for patent documents to be published, and patent databases can add data only after those documents are published.

It is worthwhile to conduct individual analysis as well. AIST is cited the most out of the three public research institutes of interest. The number of Japanese applicants that cite AIST's patents increases rapidly between 1984 and 1989. There is a moderate increase from 1990 to 2000 because this time period covers when the bubble economy in Japan collapsed and firms started to strategically file patents with a selection and concentration strategy. Further, on 1 January 1988, patent law in Japan was amended from 'one patent = one claim' to 'one patent = multiple claims'. Accordingly, it is easy to conceive how and why the number of patent applications drops after this policy change. However, the AIST trend is upwards from 1998 until 2005. To explain, R&D investment in Japan had been increasing since 1994.[2] as a result of which a lot of patents had been filed since then (Japan Patent Office, 2007).

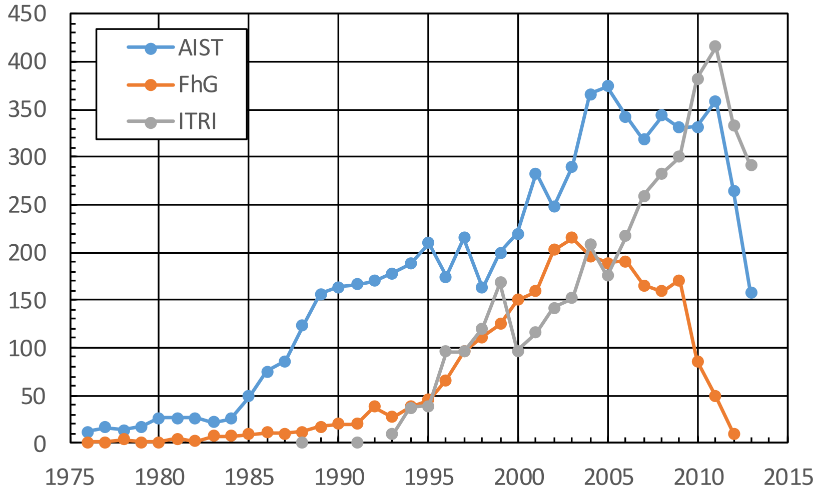
Second, the number of patent applications that cite Fraunhofer's patents continues to increase until 2003, However, subsequently it is characterised by plateau and decline. We assume that the macroeconomic context is being reflected here: the German economy between 2002 and 2003 was as unfavourable as it was during the onset of the financial crisis in 2008, which was exemplified by the fall of Lehman Brothers, amongst many others.

Lastly, ITRI shows a remarkable increase over time, excepting a blip in 2000. That is, the number of patent applications that cite ITRI's patents is ever increasing.

---

[2] See Japan Patent Office Annual Report 2007 Part 2 Government Efforts in Intellectual Property Activities. Available at: https://www.jpo.go.jp/shiryou_e/toushin_e/kenkyukai_e/pdf/annual_report2007/part2.pdf

Figure 4. Patent Applications by Domestic Applicants that Cite Patent Documents by AIST, Fraunhofer, and ITRI



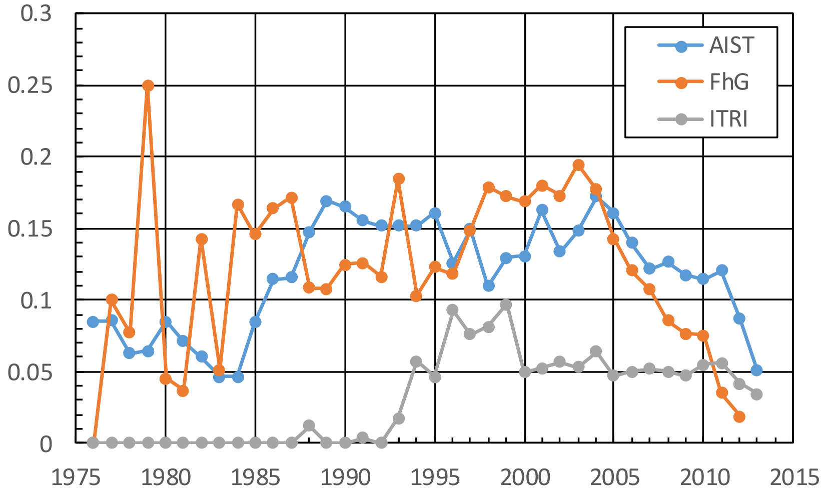
AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

Figure 5 shows the ratio of actually cited patents to all existing patents by AIST, Fraunhofer, and ITRI. In other words, Figure 5 shows the value obtained by dividing the values in Figure 4 with the number of citable patents by the three institutes. One limitation of Figure 4 is that if an applicant files many patents, the applicant's patents have a greater chance of being cited compared to an applicant with one or few patents. Figure 5 removes this bias and compares AIST, Fraunhofer, and ITRI in a fair manner. For example, until 1995, a patent application by AIST was likely to be cited in 0.16 patent applications by applicants from Japan while a patent application by Fraunhofer and ITRI was cited in 0.12 and 0.5 applications by applicants in Germany and Taiwan, respectively.

First, the AIST and Fraunhofer trends are similar after 1985, remaining in the region of 0.1–0.2 even though the variability in the Fraunhofer trend is more pronounced. This implies that their impact on domestic players was reasonably consistent. However, after 2005, both trends are downwards. One reason is that the number of patent applications by AIST and Fraunhofer increased much more than citing patents. Another reason is that the number of patent applications by domestic applicants that cite AIST's and Fraunhofer's patent applications decreases (as seen in Figure 4). However, it is not clear if the decrease is specific to Japan and Germany or common globally. Thus whether, why, and how AIST's and Fraunhofer's impacts on domestic applicants are changing warrants future study.

Moving on, ITRI's trend remains in the region of 0.05 after 2000. Accordingly, ITRI's impact on domestic applicants is reasonably consistent. This indicates that the number of patent applications by domestic applicants that cite ITRI's patent documents is increasing as much as ITRI increases its patent filings (as seen in Figure 1).

Figure 5. Ratio of actually cited patents by domestic applicants to all existing patents by AIST, Fraunhofer, and ITRI



AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

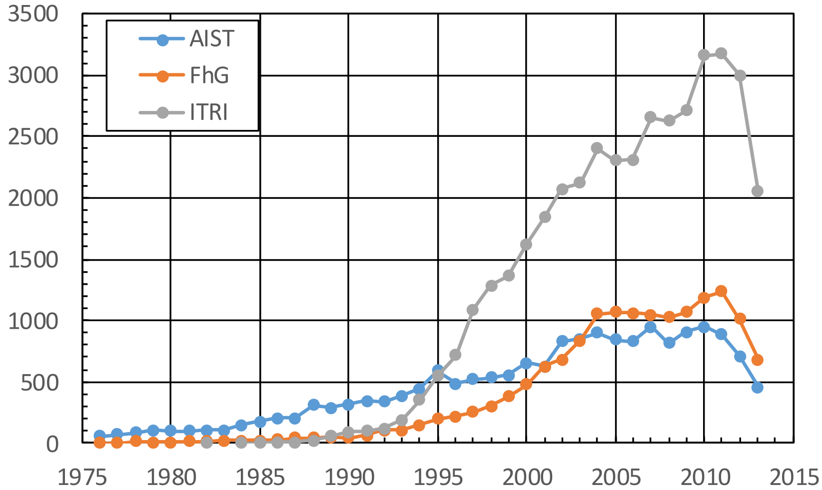
4.5.2. Oversea firms

The analysis in this subsection focuses on knowledge spillovers to overseas applicants. The results are shown in Figure 6 in terms of the number of patent applications outside Japan, Germany, and Taiwan that cite AIST's, Fraunhofer's, and ITRI's patents, respectively. For example, in 2005, about 2,300 patent applications from non-Japanese applicants cited AIST's patents, 1,100 from non-German applicants cited Fraunhofer's patents, and 800 from non-Taiwanese applicants cited ITRI's patents.

What is readily observed from the three public research institutes of interest is the number of patent applications that cited their patent documents is increasing as times goes. Thus, their impacts outside of their home countries are increasing. However, AIST's and Fraunhofer's trends are relatively stable after 2002 and 2004, respectively. Meanwhile, ITRI's trend exhibits a remarkable increase: because ITRI files a lot of patents with USPTO, the institute has many patents to cite compared to AIST and Fraunhofer. In addition, as seen in Figure 4, the number of patent applications that cite AIST's, Fraunhofer's, and ITRI's patent documents is decreasing due to the incompleteness of the patent databases.

AIST receives more citations than Fraunhofer until 2003, following which the former takes the lead. This implies that their global impacts could have exhibited similar trends and changes.

Figure 6. Patent Applications by Foreign Applicants that Cite Patent Documents by Each of AIST, Fraunhofer, and ITRI



AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

Figure 7 shows the ratio of actually cited patents to all existing patents by AIST, Fraunhofer, and ITRI. In other words, Figure 7 shows the value obtained by dividing the values in Figure 6 with the number of citable patents by the three institutes. One limitation of Figure 6 is that if an applicant files many patents, the applicant's patents have more chances of being cited compared to an applicant with zero or few patents. Figure 7 removes such bias and compares AIST, Fraunhofer, and ITRI in a fair manner. For example, until 2005, a patent application by AIST, Fraunhofer, and ITRI is likely to be cited in 0.4, 0.9, and 0.6 patent applications by foreign applicants, respectively.

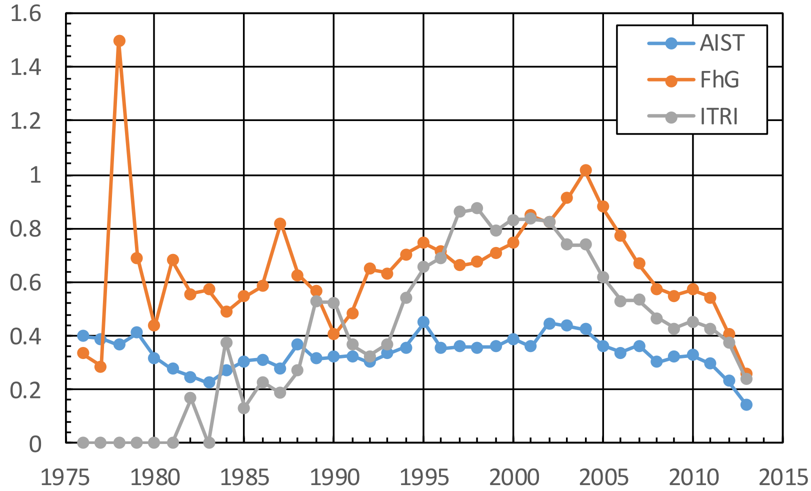
A common trend is to slope downwards after 2005. This is because the increase in the number of patent applications by AIST, Fraunhofer, and ITRI was much larger than that of citing patents.

AIST's trend is subordinate, but consistent, over the period of interest. That is, AIST had the least impact on foreign applicants compared to Fraunhofer and ITRI.

Fraunhofer's trend dominates over the period of interest. That is, Fraunhofer had the largest impact to foreign applicants. However, the variation in this trend is large, so Fraunhofer's performance is affected significantly by applied research tendencies in each era.

Lastly, ITRI's trend presents the largest increase from the 1980s to 2000, winning over Fraunhofer between 1996 and 2001.

Figure 7. Ratio of Actually Cited Patents by Foreign Applicants to All Existing Patents by AIST, Fraunhofer, and ITRI



AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

4.6. Patent citation analysis 4: technological fields – generality versus originality

This subsection analyses the generality and originality of AIST's, Fraunhofer's, and ITRI's inventions. Trajtenberg et al. (1997) defined generality in terms of how subsequent inventions spread across different technological fields, and originality in terms of how back-up inventions spread across different technological fields. If generality (originality) is substantial, the technical advances (roots) of the originating invention are broad (concentrated). The Herfindahl index operationalises these concepts as follows:

$$\text{Generality:}\quad Gen_i = 1 - \sum_{k=1}^{N_{g,i}} \left(\frac{N_{citing,i}(k)}{N_{Citing,i}} \right)^2$$

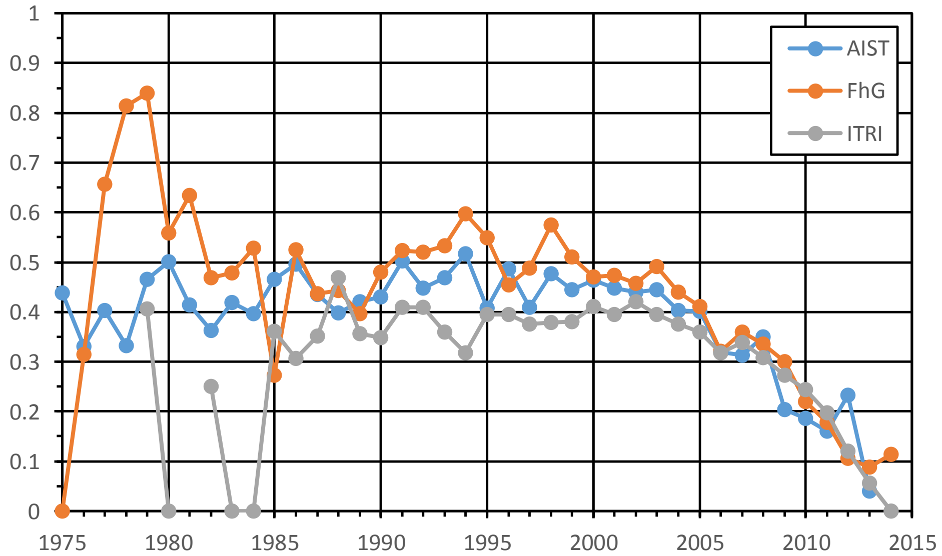
$$\text{Originality:}\quad Org_i = 1 - \sum_{k=1}^{N_{o,i}} \left(\frac{N_{cited,i}(k)}{N_{Cited,i}} \right)^2,$$

where k, N_g, N_{citing}, N_o, and N_{cited} are patent class indices: the number of different classes to which the citing patents belongs, the number of citing patents, the number of different classes to which the cited patents belong, and the number of cited patents, respectively.

First, generality of the inventions by AIST, Fraunhofer, and ITRI is compared. In this analysis, average organisational generality is calculated per application year (Figure 8).

Different tendencies are observed before and after 2000. First, until 2000, of the three public research institute of interest, the highest generality value is associated with Fraunhofer, followed by AIST and ITRI. After 2000, the generality of the inventions by all three organisations falls. It seems that they are shifting towards more applied research, rather than basic research.

Figure 8. Generality of Inventions by AIST, Fraunhofer, and ITRI



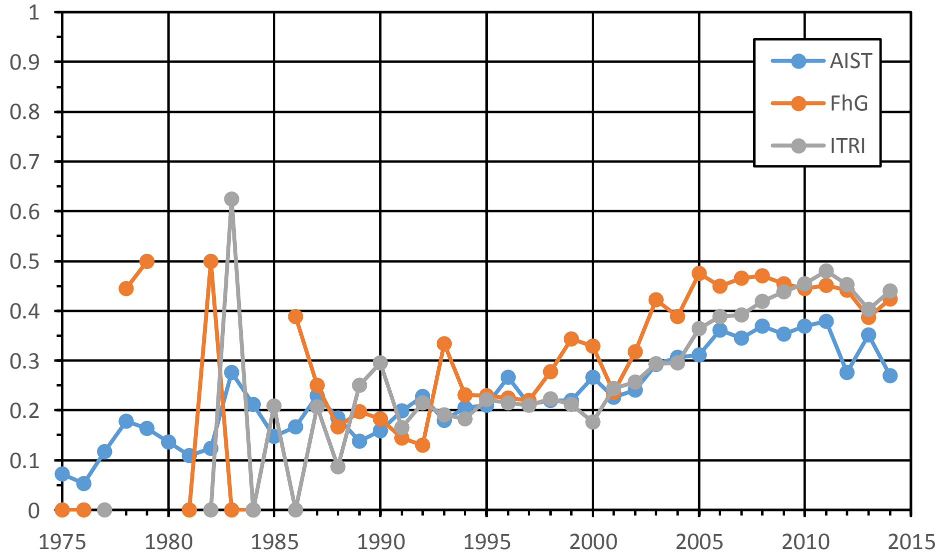
AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

Second, originality of the inventions of AIST, Fraunhofer, and ITRI is compared. As was the generality analysis, the average organisational originality is calculated per application year (Figure 9).

Different tendencies are again observed before and after 2000. Originality of AIST's, Fraunhofer's, and ITRI's inventions remain constant until 2000. There is no big gap amongst them. However, their inventions commonly increase originality after 2000. Fraunhofer shows a sudden increase in the early 2000s, and ITRI shows a constant increase every year. Even though the increase is smaller than Fraunhofer's and ITRI's, AIST's inventions also increase in originality every year. The primary reason is probably that the technological fields in which AIST, Fraunhofer, and ITRI heavily file patent applications are in the ICT industry. Those technological fields demonstrate active convergence between technologies

(Gambardella and Torrisi, 1998). Technological convergence is one method in applied research that achieves innovation by applying conventional methods to new technologies.

Figure 9. Originality of Inventions by AIST, Fraunhofer, and ITRI



AIST = National Institute of Advanced Industrial Science and Technology (Japan), FhG = Fraunhofer-Gesellschaft (Germany), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's calculations.

5. Discussion

Table 4 summarises the findings in the previous section. Some findings are worth further discussion. We must note that generalisation of our findings and discussion is difficult because the background of each country is different, and public research institutes are heterogeneous in various important respects. Understanding this limitation, we discuss the findings that are relevant to the conceptual framework explained in section 2.3.

Table 4. Summary of Findings

Indicator	AIST	Fraunhofer	ITRI
Patent applications to USPTO	Consistent over time	Increasing after 1990	Rapidly increasing after 1990
No. of co-applicants	464	186	152
No. of co-applications	996	375	622
Characteristics of co-applications	Often collaborations with domestic firms	・Often collaborations with domestic firms ・Many collaborations with foreign institutes and universities	・Often collaborations with domestic firms ・Many collaborations with institutes and universities
Knowledge origin	・Shifted from the United States to domestic sources	・Shifted from Europe, especially Germany, to abroad	・Increasing reliance on domestic sources ・High reliance on the United States, Europe, and Japan
Knowledge accumulation	・High accumulation	・High accumulation	・Low accumulation, but increasing
Knowledge spillover	・Concentrated to domestic firms ・Recently, citations per application drops	・Total citations by domestic and foreign inventions increase ・Recently, citations per application drops	・Total citations by domestic and foreign inventions increase ・Recently, citations per application drops
Generality of inventions	Decreasing	Decreasing	Decreasing
Originality of inventions	Increasing	Increasing	Decreasing

AIST = National Institute of Advanced Industrial Science and Technology (Japan), ITRI = Industrial Technology Research Institute (Taiwan).
Source: Author's construction.

5.1. Contribution to domestic and international firms through collaboration

As Figure 2 indicates, almost all of AIST's and ITRI's collaborators are domestic organisations, while Fraunhofer works equally with both domestic and foreign organisations. Their choice of collaborator may be attributed to the funding system of each institute. Since AIST and ITRI rely on national funds, their primary focus is on domestic needs, as expected by government organisations. Accordingly, it is natural for AIST and ITRI to work primarily with domestic organisations. On the other hand, Fraunhofer receives the largest proportion of its funding from the industry. Accordingly, it is natural for Fraunhofer to work with any organisations, irrespective of whether the collaborators are from Germany.

However, in the future, if government endowment declines further, AIST and ITRI increasingly will need to find additional foreign partners. Working with foreign organisations is more difficult than working with domestic organisations due to the geographical distance, lack of shared knowledge about institutional conditions, lack of shared language and work culture, and weak personnel-level networks. Both AIST and ITRI need to prepare for working with foreign partners when seeking diverse external sources of revenue.

5.2. Knowledge accumulation and spillover

As Figure 3 indicates, knowledge accumulation in AIST is better than in Fraunhofer and ITRI. Due to the hiring conditions of those institutes, this result is to be expected. The conceptual framework in section 2.3 identified researchers as a determinant for the success of public research institutes and their hiring conditions as a factor affecting knowledge accumulation. Most researchers in AIST are tenured, while those in Fraunhofer and ITRI are fixed-term. Therefore, it is natural to expect knowledge accumulation to be better in AIST than in Fraunhofer and ITRI.

However, knowledge accumulation is not the only role of public research institutes. Knowledge transfer is also important. This can occur through the mobility of researchers, licensing technologies, and interactions with industries. Therefore, it is important find a balance between knowledge accumulation and knowledge transfer based on the mission and resources of public research institutes.

5.3. Research direction

One similarity amongst the three institutes is the characteristics of their patent outcomes. As seen in Figure 8, their R&D outcomes now have less generality than before. The figure indicates that AIST, Fraunhofer, and ITRI have also conducted notable basic research, but after 2000 their focus moved increasingly towards applied research. That implies that they placed emphasis on outcomes targeted to special technological purposes.

Emphasis on applied research should not result in undermining basic research. There is concern that following a move towards a market-based mechanism, investment in basic research is decreasing (Nelson, 2004). This can be observed in many countries, including Germany, Japan, and Taiwan, and is largely due to the decline in government investment in the scientific community stemming from financial pressure. However, scientific progress has long been considered to be a key contributor to a nation's prosperity (Bush, 1945). Scientific knowledge produced from basic research is the foundation of applied research and can be beneficial to the whole of society for a very long time. Since private organisations have little incentive to conduct basic research, they can only be supported by public research institutes. Accordingly, an environment in which to conduct basic research must be provided to public research institutes.

6. Conclusions

This study investigates how public research institutes contribute innovation in NIS using AIST, Fraunhofer, and ITRI as case studies. Using patent data, this paper analyses the innovation processes of the three institutes. Some findings are unique to each institute; others are common to all of them. Based on the conceptual framework, the findings discuss three points: 1) contribution to domestic and international firms through collaboration, 2) knowledge accumulation and spillover, and 3) research direction. Policy implications are derived to better utilise public research institutes for NIS.

This study has some limitations. First, it uses only patent data to analyse the performance of public research institutes. Patent data have merits such as providing raw data regarding innovation process at a low cost. However, patent documents are only one type of research output that emanates from public research institutes. As mentioned in section 2.3, how to assess the performance of public research institutes has been a concern amongst policymakers. Accordingly, proper indicators to undertake such an assessment must be studied in the future.

Second, of all patent data, this study uses only those filed with USPTO. The reason is to make an international comparison without home biases. The US is one of the most important markets for firms doing international business. In this sense, using USPTO patents is a fair choice. On the other hand, as a trade-off, USPTO patents represent only a part of all the patent applications with all patent offices. If further detailed analysis is needed in terms of AIST, Fraunhofer, and ITRI, then focusing on their home patent offices may be pertinent.

Third, this study is limited to analysis at the applicant level. Sometimes, analysing at the inventor level can provide further insights to understand innovation processes. For example, analysing inventor networks will allow determination of 'star inventors' who lead R&D projects, understand their involvement in innovation processes, mobility of personnel between organisations, and so on. Those analyses, again, remain a future research agenda.

Lastly, there is also a limitation to the use of citation data. It takes a great deal of time (up to 10 years) for a patent document to be cited by subsequent inventions. However, there is no way to overcome this issue, except to wait for another decade to pass until more citations are added. Reproducing the current study with more reliable data also remains a future research agenda.

References

van Beers, C., E. Berghäll, and T. Poot (2008), 'R&D Internationalization, R&D Collaboration and Public Knowledge Institutions in Small Economies: Evidence from Finland and the Netherlands', *Research Policy,* 37(2), pp.294–308.

Behrens, T.R. and D.O. Gray (2001), 'Unintended Consequences of Cooperative Research: Impact of Industry Sponsorship on Climate for Academic Freedom and other Graduate Student Outcome', *Research Policy,* 30(2), pp.179–99.

Beise, M., and H. Stahl (1999), 'Public Research Industrial Innovations in Germany', *Research Policy,* 28(4), pp.397–422.

Bernardes, A. and E.M. Albuquerque (2003), 'Cross-over, Thresholds and Interactions between Science and Technology: Lessons for Less-developed Countries', *Research Policy,* 32(5), pp.865–85.

Bush, V. (1945), *Science – The Endless Frontier*. Washington, DC: United States Government Printing Office.

Chen, C.-F., and G. Sewell (1996), 'Strategies for technological development in South Korea and Taiwan: The case of semiconductors', *Research Policy,* 25(5), pp. 759–783.

Chung, K., and K. Lee (1999), 'Mid-entry technology strategy: the Korean experience with CDMA', *R&D Management,* 29(4), pp. 353–363.

Cohen, W.M. and D.A. Levinthal (1990), 'Absorptive Capacity: A New Perspective on Learning and innovation', *Administrative Science Quarterly,* 35, pp.128–52.

Cohen, W.M., R.R. Nelson, and J.P Walsh (2002), 'Links and Impacts: The Influence of Public Research on Industrial R&D', *Management Science,* 48(1), pp.1–23.

Diez, J.R. (2000), 'The Importance of Public Research Institutes in Innovative Networks – Empirical Results from the Metropolitan Innovation Systems Barcelona, Stockholm and Vienna', *European Planning Studies* 8(4), pp.451–63.

Fontana, R., A. Nuvolari, and B. Verspagen (2009), 'Mapping Technological Trajectories as Patent Citation Networks: An Application to Data Communication Standards', *Economics of Innovation and New Technology,* 18(4), pp.311–36.

Freeman, C. (1987), *Technology and Economic Performance: Lessons from Japan*. London: Pinter.

Fung, M.K. and W.W. Chow (2002), 'Measuring the Intensity of Knowledge Flow with Patent Statistics', *Economics Letters*, 74(3), pp.353–58.

Gambardella, A. and S. Torrisi (1998), 'Does Technological Convergence Imply Convergence in Markets? Evidence from the Electronics Industry', *Research Policy,* 27(5), pp.445–63.

Griliches, Z. (1990), 'Patent Statistics as Economic Indicators: A Survey', *Journal of Economic Literature,* 28(4), pp.1661–707.

Hedge, D. and B. Sampat (2008), 'Examiner Citations, Applicant Citations, and the Private Value of Patents', *Economics Letters,* 105(3), pp.287–89.

Intarakumnerd, P. and P. Chairatana (2008), 'Shifting S&T Policy Paradigm: An Experience of a RTO in Thailand', *International Journal of Technology and Globalisation,* 4(2), pp.121–38.

Intarakumnerd, P. and A. Goto (2016), 'Role of Public Research Institutes in National Innovation Systems in Industrialized Countries: The Case of Fraunhofer, NIST, CSIRO, AIST, and ITRI'. RIETI Discussion Paper Series 16-E-41. Available at: https://www.rieti.go.jp/en/publications/summary/16030050.html.

Jaffe, A.B. and M. Trajtenberg (2002), *Patents, Citations & Innovations: A Window on the Knowledge Economy*. Cambridge, MA: MIT Press.

Japan Patent Office (2007), Japan Patent Office Annual Report 2006. Available at: https://www.jpo.go.jp/shiryou_e/toushin_e/kenkyukai_e/annual_report2006.htm

Kang, B. (2015), 'The Innovation process of Huawei and ZTE: Patent Data Analysis', *China Economic Review,* 36, pp.378–93.

Kang, B. and G. Tarasconi (2016), 'PATSTAT Revisited: Suggestions for Better Usage', *World Patent Information,* 46, pp.56–63.

Kim, L. (1997), *Imitation to Innovation: The Dynamics of Korea's Technological Learning*. Cambridge, MA: Harvard Business School Press.

Kim Y.K. and K. Lee (2015), 'Different Impacts of Scientific and Technological Knowledge on Economic Growth: Contrasting Science and Technology Policy in East Asia and Latin America', *Asian Economic Policy Review* 10(1), pp 43–66.

Kline, S.J. (1985), 'Innovation is Not a Linear Process', *Research Management,* 28(4), pp.36–45.

Layne-Farrar, A. (2011), 'Innovative or Indefensible? An Empirical Assessment of Patenting within Standard Setting', *International Journal of IT Standards and Standardization Research,* 9(2), pp.1–18.

Martinelli, A. (2011), 'An Emerging Paradigm or just Another Trajectory? Understanding the Nature of Technological Changes using Engineering Heuristics in the Telecommunications Switching Industry', *Research Policy,* 41(2), pp.414–29.

Mazzoleni, R. and R.R. Nelson (2007), 'Public Research Institute and Economic Catch-up' *Research Policy* 36(10), pp.1512–28.

Michel, J. and B. Bettels (2001), 'Patent Citation Analysis: A Close Look at the Basic Input Data from Patent Search Report', *Scientometrics,* 51(1), pp.185–201.

Mock, D. (2005), *The Qualcomm Equation: How a Fledgling Telecom Company Forged a New Path to Big Profits and Market Dominance*. New York: American Management Association.

Mowery, D.C. (2010), 'Military R&D and innovation', In B.H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation* Volume 2. Amsterdam: Elsevier, pp.1219–56.

Mowery, D.C. and T. Simcoe (2002), 'Is the Internet a US invention? – An Economic and Technological History of Computer Networking', *Research Policy*, 31(8–9), pp.1369–87.

Nagaoka, S., K. Motohashi, and A. Goto (2010), 'Patent Statistics as an Innovation Indicator', In B.H. Hall and N. Rosenberg (eds.), *Handbook of the Economics of Innovation* Volume 2. Amsterdam: Elsevier, pp.1083–128.

Nelson, R.R. (1993), *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.

Nelson, R.R. (2004), 'The Market Economy, and the Scientific Common', *Research Policy,* 33(3), pp.455–71.

Nelson, A.J. (2009), 'Measuring Knowledge Spillovers: What Patents, Licenses and Publications Reveal about Innovation Diffusion', *Research Policy* 38(6), pp.994–1005.

OECD (1999), *Managing National Innovation Systems*. Paris: OECD Publishing.

Perkmann, M. et al. (2013), 'Academic Engagement and Commercialisation: A Review of the Literature on University–Industry Relations', *Research Policy,* 42(2), pp.423–42.

Ribeiro, L.C., R.M. Ruiz, A.T. Bernardes, and E.M. Albuquerque (2006), 'Science in the Developing World: Running Twice as Fast?', *Computing in Science and Engineering,* 8(4), pp.86–92.

Roessner, J.D. (1993), 'What Companies Want from the Federal Labs', *Issues in Science and Technology,* 10(1), pp.37–42.

Tanaka, M. (1989), ‘Japanese-style Evaluation Systems for R&D Projects: The MITI Experience’, *Research Policy,* 18(6), pp.361–78.

Trajtenberg, M., R. Henderson, and A. Jaffe (1997). ‘University Versus Corporate Patents: A Window on the Basicness of Invention’, *Economics of Innovation and New Technology* 5(1), pp.19–50.

Verspagen, B. (2007). ‘Mapping Technological Trajectories as Patent Citation Networks: A Study on the History of Fuel Cell Research’, *Advances in Complex Systems,* 10, pp.93–115.

Wong, C.-Y., M.-C. Hu, and J.-W. Shiu (2015), ‘Collaboration between Public Research Institutes and Universities: A Study of Industrial Technology Research Institute, Taiwan’, *Science, Technology & Society,* 20(2), pp.161–81.

Yang, C.-H., K. Motohashi, and J.-R. Chen (2009), ‘Are New Technology-based Firms Located on Science Parks Really More Innovative?: Evidence from Taiwan’, *Research Policy,* 38(1), pp.77–85.

Yoo, Y., K. Lyytinen, and H. Yang (2005), ‘The Role of Standards in Innovation and Diffusion of Broadband Mobile Services: The Case of South Korea’, *Journal of Strategic Information Systems,* 14, pp.323–53.

ERIA Discussion Paper Series

No.	Author(s)	Title	Year
2018-10	Byeongwoo KANG	Innovation Process in Public Research Institute: Case Studies of AIST, Fraunhofer, and ITRI	Mar 2019
2018-09	Ha Thi Tan DOAN and TRINH Quang Long	Technical Change, Exports, and Employment Growth in China: A Structural Decomposition Analysis	Feb 2019
2018-08	Ha Thi Tan DOAN	Multi-product Firms, Tariff Liberalisation, and Product Churning in Vietnamese Manufacturing	Feb 2019
2018-07	DUONG Lan Huong, Tsunehiro OTSUKI and Etsuyo MICHIDA	Quantitative Assessment of the Impact of EMS Standards on the Firms' Attitude towards Product Safety	Feb 2019
2018-06	Nobuya FUKUGAWA, Masahito AMBASHI and Yuanita SUHUD	Division of Labour Amongst Innovation Intermediaries in Agricultural Innovation Systems: The Case of Indonesia	Nov 2018
2018-05	Masako NUMATA, Masahiro SUGIYAMA, Gento MOGI, Wunna SWE and Venkatachalam ANBUMOZHI	Technoeconomic Assessment of Microdrigrids in Myanmar	July 2018
2018-04	Rashesh SHRESTHA and Ian COXHEAD	Can Indonesia Secure a Development Divided from its Resource Export Boom?	June 2018
2018-03	Ayako OBASHI and Fukunari KIMURA	Are Production Networks Passé in East Asia? Not Yet	June 2018
2018-02	Lili Yan ING, Wei TIAN, Miaojie YU	China's Processing Trade and Value Chains	May 2018
2018-01	Richard POMFRET	The Eurasian Land Bridge The Role of Service Providers in Linking the Regional Value Chains in East Asia and the European Union	May 2018

Previous year of ERIA Discussion Paper, can be found at:
http://www.eria.org/publications/category/discussion-papers