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Innovation and Public Research Institutes: Cases of AIST, RIKEN, and JAXA[*]

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Abstract

In this paper, we focus on three large public research institutes (PRIs) in Japan—National Institute of Advanced Industrial Science and Technology (AIST), the Institute of Physical and Chemical Research (RIKEN), and the Japan Aerospace Exploration Agency (JAXA)—and investigate their roles in helping Japan's industry by examining their patents. First, the background and history of the development of these institutions are described briefly. We employ four measures drawn from patent data (inventor forward citation, examiner forward citation, family size, and generality index) to describe the inventive activities of PRIs. Universities' and firms' patents are used as benchmarks. The impact of the PRIs' research collaboration with the private sector is analyzed as well. We found that each of the three PRIs has been playing a unique role in Japan's innovation system. In addition, we found out that universities' patenting activity has been facing difficulties particularly in recent years. Finally, we discuss the factors that might affect the research outcome.

Keywords: Public research institute, University, Patent, Research collaboration

JEL classification: O34, O32

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1. Introduction

Among the actors in the National Innovation System (NIS), the Public Research Institute (PRI) is probably the least studied. Recently, many researchers inquired changing role of universities in the National Innovation System. In comparison, research on the role of PRIs in the NIS is rather limited. Much of that research focuses on the PRI's role in developing countries' NIS. Notable exceptions include Rush et al. (1996), whose chapters examined PRIs in Germany, the United Kingdom, and the United States, among others. Jaffe et al. (1998) used patent statistics to evaluate NASA's support of industry technology, although whether it is appropriate to classify NASA as a PRI is debatable.

In Japan, the total amount of R&D spending in 2010 was 17 trillion yen, 70.2% of which industry has spent. Universities and colleges have spent 20.1%, and public organizations have spent 8.3%. Still, it uses 40% of government R&D, while universities spend 53% and firms spend 5%. It employs 32.422 researchers, which is 3.8% of the total number of researchers in Japan, while the firms' share is 58.2% and the universities' share is 37.0%. PRI researchers spent more R&D per researcher, 90.98 million yen, compared to 12.09 million yen per university researcher and 24.48 million yen per researcher in the business sector. While most university researchers spend a certain amount of time teaching and engaging in activities other than research,[2] researchers at PRIs have more time to concentrate on their research, although we do not have the data to support this.

Historically, PRIs conducted research related to government missions, including defense, space exploration, health care, agriculture, and industrial technology. PRIs that aimed to help industry played an important role to help industries upgrade their technology. For instance, Odagiri and Goto (1996) introduced a case where Electro-Technical Laboratory (ETL) researchers contributed to the development of semiconductors.[3] The ETL is a part of the National Institute of Advanced Industrial Science and Technology (AIST) today, which is one of

[2] According to a survey by the Ministry of Education, university faculties spent only 36.1% of their working hours on research in 2008 (NISTEP-MRI, H21.3).
[3] See Chapter 8, Electrical and Communications Equipment, in Hiroyuki Odagiri and Akira Goto, Technology and Industrial Development in Japan, Clarendon Press, Oxford, 1996.

the three PRIs we will examine in this paper.

However, throughout the 1970s and 1980s, as Japanese firms' technological capabilities were enhanced and reached technological frontiers with increasing financial resources, their reliance on PRIs as a source of advanced technology decreased. Universities' growing research capability and their close ties with firms also obscured the role of PRI in post catch-up Japan. This is particularly true for PRIs whose mission is to promote industrial technology.

Another factor that influenced the discussion on the proper role of PRIs was increasingly intense trade conflict with the United States. The United States criticized the Japanese government for its "mercantilist" policy and outright government assistance to industry. In response, the Japanese government shifted research at PRIs toward basic research from research closely related to industrial needs. This trend was further compounded by the perception that Japanese industries had finally reached the technological frontier and it had to create technology on its own rather than depending on foreign technology. As a result, government research institutes that were working closely with industry started to emphasize basic research.

This trend changed again after the economic downturn in the early 1990s and prolonged recession that followed for more than a decade. Because of the recession and aging population, government deficit increased substantially. Thus, public spending was scrutinized to ensure the government was bringing in "value for money." There was a simultaneous trend toward privatization, more use of market, and smaller government, further questioning the rationale of PRIs.

Presently, there is an ongoing discussion about the role and rationale of PRIs in Japan's innovation system. Whether it will remain a research institute, evolve into something unique, or transform into a technology service organization still remains to be seen in Japan.

In this paper, we focus on three major PRIs in Japan: the National Institute of Advanced Industrial Science and Technology (AIST), the Institute of Physical and Chemical Research (RIKEN), and the Japan Aerospace Exploration Agency (JAXA). Specifically, we investigate their role in helping Japan's industry by examining their patents. First, however, we will provide a brief overview of the three PRIs.

2. A brief history of three institutes

In this section, we briefly describe the three PRIs' history, current status, and their patenting activity. Also included is a brief description of Japanese universities' patenting activity since we use the university sector as a benchmark to compare the three institutes' performance.

We identified patent applications of the three PRIs and universities by checking applicant name, applicant address, and inventor address in the patent bibliographic information using the IIP patent database.[4]

2-1. AIST

Although some of the laboratories constituting AIST were established more than 100 years ago, the direct precursor of AIST—the Industrial Technology Agency (ITA)—was established in 1948. Following a succession of restructuring as well as a name change, a large laboratory was built in Tsukuba in 1980, which is 50 km outside Tokyo. At that time, it was a science city in the making. In 2001, it was incorporated as an independent administrative agency upon the integration of the 15 laboratories under the auspices of the Ministry of Economy, Trade and Industry (METI).

AIST's main mission is to explore next-generation key technologies through advanced research in leading-edge industries in such fields as electronics, information, machinery, environment, and biotechnology, and through interdisciplinary research. As a public research institute, AIST functions as a platform for developing technologies for innovation in Japan and is proactive as an organization that directly promotes such innovations in industry.

AIST and its predecessor ITA have a long history of contribution in planning, coordinating, and promoting many large-scale national R&D projects, most of which are organized as research associations. Most research associations in Japan are created by the METI (formerly MITI) initiative to coordinate industrial participation in a specific METI large-scale project. A

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[4] We used the beta version of IIP database. The latest published version is available for academic use from the website of the Institute of Intellectual Property: http://www.iip.or.jp/e/e_patentdb/

notable example is the VLSI Research Association formed in 1976. AIST has a section devoted to conducting research to develop national standards such as mass, length, time, electricity, temperature, luminous intensity, and amount of substance.

AIST's annual budget was 90 billion yen in 2012, and it employs 2,500 researchers. About 79% of its revenue comes from the government, and 14% comes from industry. AIST accepts 4,600 visiting researchers from other organizations through the industry/academia/government partnership (1,700 from industry, 2,100 from academia, and 900 from other PRIs) in 2012.

AIST and its predecessor ITA applied patents actively for quite some time. Figure 1 shows the general trend in patent applications in Japan from 1971 to 2010, overlaid with 2 sets of patent series concerning AIST: the number of patent applications by AIST/ITA and the number of joint patent applications by AIST/ITA and private firms. The periods of some of the well-known large-scale R&D projects are also shown. (The "Sunshine" and "Moonlight" programs were collections of large-scale R&D projects that focused on new energy sources and the effective use of energy following the oil crisis.)

The total number of patent applications in Japan grew rapidly from the late 1970s to 1990, declining somewhat in the early 1990s. This decline in the early 1990s may have been due to introducing an improved multiple claim system in 1987, and to administrative guidance to reduce patent applications since JPO had backlogs of applications to be examined. The number of patent applications surged again in the late 1990s, peaked in 2001, and then declined in the 2000s. The number of patents applied for in 2009 and 2010 in this chart is not reliable, as our dataset does not fully cover them.

As shown in Figure 1, AIST's number of patent applications has two distinct peaks. The first peak is seen in 1985 and the second in 2003. The 1980s can be regarded as the "golden age" for AIST/ITA, just after it relocated to the new Tsukuba Center and participated in many large-scale projects, such as the Sunshine and Moonlight projects and fifth-generation computer project. However, the number of joint patent applications with the private sector is greater during the second peak seen in the early 2000s.

AIST/ITA's patent applications slowed down in the mid-1990s, a dip seen in other PRIs and in the overall number of patent applications in Japan. A possible reason is the adoption of an improved multiple claim system in 1988. After this change, the number of claims in a patent increased, and possibly decreased the total number of patent applications. In addition, for PRIs, the emphasis on basic research mentioned before might have resulted in the decrease of patent applications. In the latter half of the 1990s, the importance of patents was emphasized in Japan, following the introduction of the Bye-Dole Act and so-called pro patent policy in the U.S. in the 1980. In 1998, Technology Transfer Promotion Act (TLO Act) was enacted in Japan, and universities and PRIs were encouraged to apply patents and transfer technology through licensing. This may be reflected in the increase of patent applications by AIST and other PRIs in the latter half of 1990s. Patent applications peaked in 2005 and started to decline afterward, partly due to a weaker Japanese economy in general and decline of electronics industry, which was the most actively patenting industry, and partly because of the shorter maximum amount of time between the filing of applications and requests for examination from seven years to three years.

(Figure 1 here)

2-2. RIKEN

RIKEN, the Institute of Physical and Chemical Research, was established in 1917 as a private foundation for the study of pure science by industrialist Eiichi Shibusawa and leading researchers, modeled on the Kaiser Wilhelm Society in Germany. The private sector and the government each provided half of the funding.[5] With increasing support from the government, RIKEN grew steadily through the 1930s and early 1940s. RIKEN is rather unique in that it created a group of companies that commercialized RIKEN's research output and then return the part of the profit to RIKEN. It was considered a Zaibatsu (conglomerate) that dominated the Japanese economy before WW2, and was dissolved after the end of WW2 by the Allied Forces. Some of the companies still exist and developed into major corporations, such as Ricoh or Kaken Pharmaceutical.

RIKEN re-incorporated in 1958 as a government-affiliated corporation for basic science and

[5] See T. Hiroshige (1973) Kagaku no Shakaishi (The Social History of Science) Tokyo, Chuo koron-sha. See also Odagiri and Goto (1996).

applied research. It relocated in 1967 to state-owned land in Wako, outside Tokyo, and in the 1980s, modeled after the Max Planck Society in Germany. It began establishing satellite institutions across the country, each focusing on a specific field of research such as genetic research, super computer, synchrotron radiation, and tissue engineering. In 1996, RIKEN generated and incubated spin-off companies, and 22 firms have been established as of 2013.

Since 2003, RIKEN has been an independent administrative agency under the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Its mission is to support excellent research in science and technology in order to contribute to the technological and economic development of the Japanese society through active partnerships with the private sector.

Until 1986, RIKEN's research staff members were permanent employees, and its number was almost stable at 400–450. RIKEN started to employ fixed-term research staff in addition to permanent staff in 1986. Since then, the number of researchers has grown rapidly, reaching about 2,900, of which 2,500 are fixed-term employees in 2012. Moreover, RIKEN accepts about 3,000 visiting researchers and graduate students every year.

In 2012, RIKEN's annual budget was about 90 billion yen. About 98% of its revenue comes from the government and 1.5% from the private sector. Its focus is toward the basic end of research, but as mentioned above it has a unique history of having created spin-off companies before WW2, and its contribution to industry has always been emphasized.

Figure 2 shows the trend in RIKEN's patent applications. Its overall pattern is somewhat similar to that of AIST. It peaked in the mid-1980s, similar to AIST, and peaked again in the mid-2000s. The second peak may have resulted from the "Arima Initiative" pursued by RIKEN's 7th president, Dr. Akito Arima, from 1993 to 1998. He emphasized RIKEN's close ties with industry in the past and encouraged patenting activity, noting that "the value of one patent equals that of ten academic papers." He lifted the ban on exclusive licensing of RIKEN's patents (on a limited-term basis) and aggressively supported generating spin-off companies and technology transfers. The proportion of RIKEN's joint patent applications with the private sector has exceeded AIST's but has gradually decreased in the 2000s.

(Figure 2 here)

2-3. JAXA

JAXA has three precursor organizations: the Institute of Space and Aeronautical Science (ISAS), the National Aerospace Laboratory of Japan (NAL), and the National Space Development Agency of Japan (NASDA).

The Institute of Space and Aeronautical Science (ISAS) was founded in the University of Tokyo in 1964. In 1970, it launched Japan's first artificial satellite, OHSUMI, and put it into orbit successfully. In 1981, ISAS was reorganized as a joint research organization among Japanese universities, and it has launched 27 scientific satellites and solar system explorers to date, including the SAKIGAKE probe to Halley's Comet and HAYABUSA probe to the asteroid ITOKAWA.

The National Aerospace Laboratory of Japan (NAL), which was established in 1955, has pursued research on aircraft, rockets, and other aeronautical transportation systems, as well as peripheral technology. NAL has also developed and improved large-scale test facilities, such as wind tunnels and super computers, and has made them available to related organizations and projects. Those examples include the NAMC YS-11 project, a turboprop airliner built by a Japanese consortium started in 1954, and the Mitsubishi Regional Jet (MRJ) project, a turbofan jet airliner built by Mitsubishi Aircraft Corporation started in 2003. The Ministry of International Trade and Industry initiated both projects.

The National Space Development Agency of Japan (NASDA) was established in 1969 to develop space and the promotion of the peaceful use of space. Its main purpose was to develop satellites (including space experiments and the space station), launch vehicles (including launching and tracking the craft), and develop methods, facilities, and equipment required for such endeavors. NASDA had successfully developed a series of liquid propellant rocket engines and launched more than 30 satellites for communication, broadcasting, weather observation, and so on. Since 1988 NASDA has been incorporated in the International Space Station program.

ISAS, NAL, and NASDA coalesced to form one independent administrative agency, JAXA, in 2003 under the auspices of MEXT. It employs 1,500 researchers with an annual budget of 180 billion yen, 99.4% of which the government provides. JAXA is different from the previous two PRIs. Not only does it conduct R&D related to space, but it also develops rockets and other products in cooperation with industry, and procures from it. In 2012 “the contribution to private sector innovation” was officially included as part of JAXA’s mission. NASDA and NAL worked closely with each other and have a long history of collaboration with the private sector. For example, NAL undertook R&D and analysis projects to design, test, and define the development steps of the key large rocket engines, which were then developed by Mitsubishi Heavy Industries or Ishikawajima-Harima Heavy Industries, two major contractors for rockets, under NASDA sponsorship. Many of the technical papers on the development of engines or components were written by JAXA engineers, even though most of the work was done by the two contractors (Sutton, 2005).

Figure 3 shows the trend in JAXA’s patent applications. Although the number of patents owned by JAXA is far smaller than those of AIST and RIKEN, it has two peaks in the 1980s and 2000s, similar to AIST and RIKEN. The obvious feature of JAXA’s patenting is the high proportion of joint applications (even higher than RIKEN’s), especially in the 1990s. This could be explained in part by the close relationship between JAXA and its contractors. Most of JAXA’s R&D activities are, in fact, the collaborative development of special hardware and software with a limited number of private firms. Joint inventions are common, although the applicability of that kind of knowledge is rather limited. The several big projects involving private firms were completed around these periods, which might be one reason why the share of joint patent decreased.

(Figure 3 here)

2-4. University

In addition to the three PRIs mentioned above, we would like to discuss the patenting activity of universities in Japan. In 2012 there were 771 universities in Japan, 86 of which are national universities. Most R&D activities are highly concentrated in these national universities, except for a few large private universities. National universities did not have the status of independent legal entity until 2003, and hence they did not have patent rights. Although formal collaborative research with private firms on a contract basis became possible for national universities only after 1983, university professors had been working closely with industries, mostly informally.

This was formalized in the late 1990s through a series of new laws and organizational changes. As mentioned above, the TLO Act enacted in 1997 allowed universities to establish a Technology Licensing Organization (TLO) to own patent rights and license them to the private sector. Subsequently, national universities themselves were incorporated as National University Corporations in 2003 and began encouraging researchers' patenting activities.

Figure 4 illustrates the sharp increase in the number of patent applications by universities (including TLOs) after 1997. About half are joint applications with private firms.

(Figure 4 here)

3. Analytical framework

According to the report by OECD, (OECD, 2011) PRIs were diversified in their main mission, size, and types of activity. Applied research was common among most institutes, although its overall importance varied across countries. As previously mentioned, AIST, RIKEN, and JAXA have different backgrounds and development histories. While each might play a distinctive role in Japan's national innovation system, they share more or less the same role as the knowledge creating and transferring intermediary.

We use four measures drawn from patent data to examine PRI performance to create, transfer and help create knowledge useful for industry. The first measure is the number of *inventor forward citations*. The inventor forward citation shows the extent technological knowledge contained in that patent is used by the subsequent inventors. For example, if a PRI generates patents with many inventor forward citations, then the PRI is considered to be providing high quality technological knowledge as public goods.

The second measure we use is the number of *examiner forward citations*. The existence of examiner forward citation means that the patent is cited by a patent examiner, mostly to eliminate subsequent patent applications. Eliminating the competitor's patent is a major reason why firms get a patent.

The third measure is the number of patent offices for which a patent invention was applied (*family size* of the patent). When an invention was expected to yield large profits in many countries, one would seek patent protection not only in Japan but also in foreign countries for the invention. If a firm's patent jointly owned with a PRI has large family size, the PRI may be considered as contributing to support the firm to invent technology with high commercial potential.

The fourth measure is the technological diversity of inventor forward citations, which is called "generality"[6]. *Generality* of patent *i* is

$$\text{Generality}_i = 1 - \sum_{j}^{n_i} s_{ij}^2 ,$$

where s_{ij} denotes the percentage of citations received by patent *i* that belong to patent class *j* out of n_i patent classes (Hall et al., 2001). Patents associated with high generality are relevant to later inventions spanning diverse technology fields and thus signal wide knowledge spillover.

We will use patents by universities and firms as benchmarks to evaluate three PRIs. While universities are eager to develop their intermediary functions these days, their primary mission is to educate and to create fundamental knowledge, and PRIs, as intermediary organizations by nature, are thought to understand the needs of the private sector better than universities.

We will see the effect of research collaboration[7] of PRIs with the private sector, which can be identified by *joint patent* applications[8]. After our interview with these research institutes, we learned that joint patent application is the result of some form of research collaboration. The fruits from research collaborations are expected to have higher technological or business value compared to those from research in private sectors, because PRIs' important mission is considered to be support of private firms' research which is difficult to conduct only by themselves. As mentioned in an earlier section, all three PRIs and universities experienced

[6] See Trajtenberg et al. (1997)

[7] There are many literature on research collaboration both on co-ownership (see, for an example, Cassiman and Reinhilde (2002), Hagedoorn, Link and Vonortas (2000) and Hagedoorn(2002)) and on the effects of research cooperation on the economic performance (see, for an example, Cockburn and Henderson (1998), Sakakibara (1997), Branstetter and Sakakibara (1998), Lerner and Merges (1998) and see a survey by Siegel (2002)). However, most studies are at firm level. This makes it difficult to assess how research collaboration actually affects the process of knowledge production, such as the scope of the knowledge used for research (Exceptions are , for example, Mowery, Oxley and Silverman (1996), Tsukada and Nagaoka (2014)). We exploit patent level sample in this paper.

[8] Wong and Singh (2013) examined impact of university-industry R&D collaboration using indicators of university-industry co-publication.

significant organizational and governance reforms in the early 2000s. In order to see the impact of these reforms, we examined the fixed-year effect *after 2001* on the performance measures.

In addition, we examined the effects of the following factors on the quality of patents, which might be related to the characteristics of research projects at the PRIs. *Science linkage*, viewed as the extent to which the inventor takes advantage of scientific knowledge, is measured by the number of inventor backward citations to non-patent literature (typically scientific papers). *Inventor backward citation* to patent literature is viewed as the extent to which the inventor can take advantage of accumulated technological knowledge. *Team size* represents the resources organization put into the project in question, which shows how a firm views the importance of the project. It can be also considered as a proxy for network effects of a research team. Generally speaking, the larger the number of a team is, the wider the network of the team becomes as a whole. We will control the differences among *technology fields* using fixed-effect dummy variables for 35 fields. We used ITC classification of WIPO as the technology field of patents, made up by linking the first IPC of the patent application with the IPC-Technology Concordance Table[9] updated in January 2013.

4. The data

Our sample consists of patent applications by three PRIs, universities, and private firms. In order to construct our sample, we used the IIP patent database, the EPO Worldwide Patent Statistical database (PATSTAT) and the patent database of the Artificial Life Laboratory Inc.[10] We identified patent applications of three PRIs, universities, and private firms by checking applicant name, applicant address, and inventor address on patent bibliographic information included in the IIP patent database. Patent applications by TLOs are treated as university patents. Private firms' patents were randomly selected, and patents applied for by foreign firms and

9 ITC links International Patent Classification symbols with thirty-five fields of technology. The Concordance Table is available from http://www.wipo.int/ipstats/en/statistics /technology_concordance.html.

10 IIP patent database is available at the website of Institute of Intellectual Property, and the detailed version of which is the patent database of the Artificial Life Laboratory, http://www.alife-lab.co.jp/.

non-corporate inventors were excluded.

Inventor citations to patent and non-patent literature were calculated using the database of the Artificial Life Laboratory Inc., which is available for patent applications published after 1993. We used number of forward citations with a 5-year window. Family size is the number of patent offices in which patent protection was sought for an invention. We counted number of authorities patent applications is filed in INPADOC family using the PATSTAT database. Generality index was calculated using all ITC classes converted from all IPCs of patents, which cite a sample patent. We focused on 77,975 patents applied for the Japanese patent office between 1992 and 2005.

Figure 5 shows the average performance measures of PRIs, universities, and firms by collaboration structure. As mentioned earlier, patents applied by PRIs jointly with firms are usually the results of collaborative research between PRIs and firms. Therefore, it is possible to assess the characteristics and effectiveness of the collaborative research by examining jointly applied patents. The inventor forward citation of the patents of AIST, RIKEN, and universities is averagely higher than that of private firms. They tend to create important technological knowledge and disclose it to the economy. Besides, joint patents of AIST or universities with firms have even higher inventor forward citation than their sole patents. Family size of joint patents of AIST, RIKEN and universities with private firms tend to be higher than their sole patents. Generality tends to be broad for patents of AIST, RIKEN and universities compared to patents applied by firms.

(Figure 5 here)

Figure 6 shows average input measure of PRIs, universities and firms by collaboration structure. Science linkage of AIST, RIKEN, or universities' patents is relatively higher than that of firm's patents. Especially, the high science linkage of RIKEN's patents is noteworthy both for their sole patents and joint patents. These reflect that research activities of PRIs and universities tend to be relatively close to basic science, compared to private firms. However, science linkages of joint patents of PRIs or universities with private firms are lower than that of patents solely owned by a PRI or university, which might suggest that PRIs and universities collaborate with private firms for research in applied or development stages. The average size of research teams yielding jointly applied patents is larger than that of the patents applied solely. PRIs and universities might contribute to providing human resources for research and transfer science based technology to industry. On the other hand, backward citations, which can be interpreted as the exploitation of existing technical knowledge, are slightly higher when PRIs or universities collaborate with firms.

(Figure 6 here)

The percentage of joint patents of AIST, RIKEN and universities with private firms does not differ between ITC sectors (Figure 7). The percentage of PRIs' or universities' joint patents is higher than that of private firms throughout observation periods, reflecting their mission as knowledge intermediary organizations. However, the share of universities' joint patents was decreasing since the TLO Act was enacted in 1997, which allows university to own patent rights and license them to the private sector.

(Figure 7 here)
(Figure 8 here)

5. Estimations

This section reports the results of estimations to assess how collaborative research between PRIs or universities and private firms enhances the performance. We estimated the following specification using data at the patent level:

$$Y_i = X_i \beta + \varepsilon_i ,$$

where Y_i is performance measure of patent i . X_i includes variables which is thought to have effects on performance variable. Four variables are used as performance measures: *inventor* *forward citations*, *examiner forward citations*, *family size*, and *generality* index. Estimation method is negative binomial regression for estimations using *inventor forward citations* and *examiner forward citations* as the dependent variable, and poisson regression for estimation using *family size* as the dependent variable, because these three dependent variables are count data. We used ordinary least square for regression using *generality* as dependent variable.

We introduced four *organization dummies* of AIST, RIKEN, JAXA, and universities, and *joint patent dummy*[11] which takes 1 if the patent was yielded through collaborative research by multiple organizations and takes 0 otherwise, and also the interaction terms of *organization dummies* and *joint patent dummy* as independent variables. Thus, the base line of the estimations is firms' sole patents. The coefficient of an organization dummy means difference in performance measure between firms' sole patents and sole patents of the PRI or university. *Joint patent dummy* captures difference in performance between firms' sole patents and firms' joint patents. The sum of coefficients of an *organization dummy* and interaction term of the *organization dummy* and *joint patent dummy* means the extent to which collaboration between firms and the PRI or university enhances performance compared to firms' joint patents. Additionally, *After2001 dummy* and interaction terms of *organization dummies*, and *After2001 dummy* are also introduced, taking into account possibility that performance was changed after 2001 in which PRIs became independent administrative agency. Thus, the coefficients of *organization dummies*, *joint patent dummy*, and the interaction terms mean the effects before 2000. Focusing on the effects after 2001, we have to take into account the coefficients of *After2001 dummy* and the interaction terms of *After2001 dummy* and *organization dummies*. The *ITC class dummies* were used to control differences by technology field. Table 1 shows the basic statistics and correlation coefficients of the sample[12].

(Table 1 here)

[11] It takes 1 if PRI/university and a private firm collaborated for the patent, or multiple private firms collaborated with each other.

[12] The number of observation of *generality* index is smaller than the other variables, since generality index can be calculated only when the patent received at least one forward citation.

5-1. Estimation results

Table 2 shows the estimation results. The coefficient of *joint patent* captures effect of collaborations by multiple private firms on performance measures. The differences between PRIs' sole patents and firm's sole patents are reflected by coefficients of organization dummies. Firms' joint patents with other firms have significantly positive effects on *inventor forward citations* and on *generality*, compared to firms' sole patents. Collaborative research between private firms significantly increases the knowledge spillover to subsequent patents in wide technological fields than firms' sole patents.

Inventor forward citation and generality index of sole patents of AIST, RIKEN and universities are significantly higher than those of firms' sole patents. These suggest that these organizations tend to yields patents with significantly higher technological values. On the other hand, family size of sole patents of AIST and universities are smaller than that of firms' sole patents. However, family size of RIKEN's sole patents is larger than firm's sole patents. JAXA's patents don't show positively significant coefficient, except for *generality* index of their sole patents.

The differences between PRIs' or universities' joint patents with firms and firms' joint patents with other firms are designated by taking into consideration the coefficient of *organization dummy* and the coefficient of interaction term of *organization dummy* and *joint patent* together. The significance levels of the difference are shown in Appendix Table A1.

Focusing on patents applied for before 2000, the year its organizational status changed, *inventor forward citation*, *examiner forward citation*, and *generality* index of AIST's and universities' joint patents are significantly higher than that of firms' joint patents. However, family size of AIST's or universities' joint patents is slightly rather lower than firms' joint patents. RIKEN's joint patents have significantly larger family size than firms' joint patents, suggesting that RIKEN's patents created through collaborations with private firms had larger market opportunity in many countries. As to other performance measures, RIKEN's joint patents did not differ with firms' joint patents.

After 2001, performance of collaboration between universities and private firms significantly decreased in terms of *inventor forward citations*, *examiner forward citations*, and *generality* index, compared to the performances before 2000.

The coefficients of input measures such as *inventor backward citations*, *science linkage* and *team size* are estimated significantly positive in all equations.

(Table 2 here)

6. Discussions

AIST's sole patents tend to have smaller family size but higher inventor forward citations and generality index compared to the private firms' sole patents. These results imply that AIST has contributed to the pool of public knowledge by creating and disseminating technological knowledge. On the other hand, when AIST applied patents jointly with private firms (joint patents), they tended to have even higher inventor forward citations and generality compared to the joint patents of private firms among themselves, although inventor forward citation and generality were not as high as those of sole patents. These results imply that AIST has contributed to business activities of the partner firm by research collaboration.

As for RIKEN, their sole patents tend to have higher inventor forward citations, family size and generality than firms' sole patents. This implies that RIKEN has contributed to pool of knowledge by supplying technological knowledge as a public good through publishing patent information, and to disseminating technological knowledge. On the other hand, when RIKEN applied joint patents, they tended to have lower inventor forward citations than RIKEN's sole patents. Spillover effects of RIKEN's patents are almost the same as the firms' joint patents. However, family size of RIKEN's joint patents was significantly larger than firms' joint patents, implying that RIKEN has contributed to partners by helping it to create technology with larger business potential.

As for JAXA, their sole patents have smaller family size than firms' sole patents. When JAXA applied patents jointly with firms, those patents tended to have even lower forward citation and smaller family size compared to joint patents of firms. These results are considered to be the consequences of the characteristics of JAXA's R&D activity, which is deeply integrated with the small number of space and aircraft firms. Such technological knowledge might be of limited applicability.

The examinations of patents of three PRIs show that each of the three public institutes has its own unique identity and is fulfilling its specific role in Japan's innovation system. Universities' sole patents tended to have higher inventor forward citation and higher generality, which correspond to university's public and basic research oriented nature. However, percentage of joint patents with firms decreased since 1997. And, when universities applied joint patents with firms, inventor forward citation and generality decreased. Joint patents at universities (almost exclusively exploited by a partner) do not contribute especially after 2001. Furthermore, the performance of universities' sole patents also decreased in terms of examiner forward citations, family size, and generality after 2001, although the number of university patents is increasing. These results might suggest that pro-patent of universities after the TLO Act produced large number of low quality patents.

We suggest that the changes in patent policies and governance of PRIs in the 2000s might have a positive impact on the forward citation and family size of AIST's patents but a negative impact on generality of universities' patents. However, it is beyond the scope of this paper to identify the specific policy effects or the governance effects against the general trend in this analysis. Further research is needed.In this paper, we found that the fundamental scientific knowledge (represented by the science linkage), accumulated technological knowledge (represented by inventor backward citation), and team size (represented by the number of inventors), increase forward citation , family size ,and generality of patents.. Activities related to these factors, such as in house basic research to a certain extent, monitoring technology trends, and networking by its researchers, should be encouraged at PRIs.

Appendix

Table A1 shows significance levels of difference between PRIs' or universities joint patents and firms' joint patents. For example, regarding the significance of difference between AIST's joint patents and firms' joint patents before 2000, we estimated the coefficient of AIST dummy using sample consisting only of AIST's joint patents applied for before 2000 and firms' joint patents applied for before 2000.

(Table A1 here)

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Tables and Figures

Figure 1. Trends in AIST's patent applications

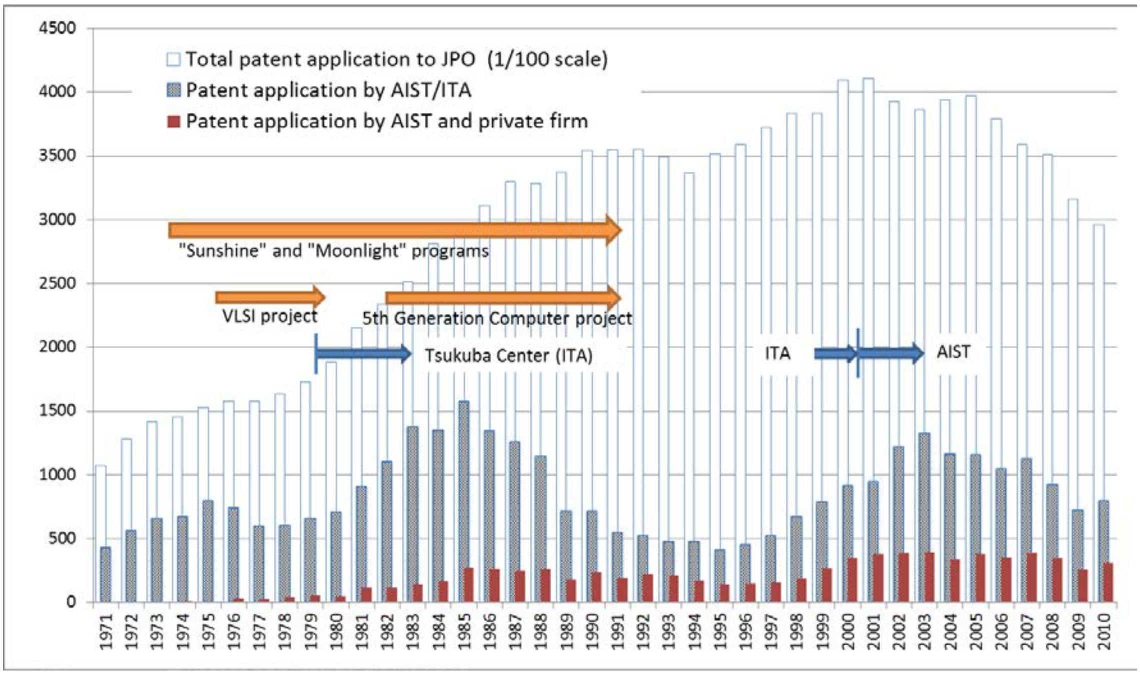

Figure 2. Trends in RIKEN's patent applications

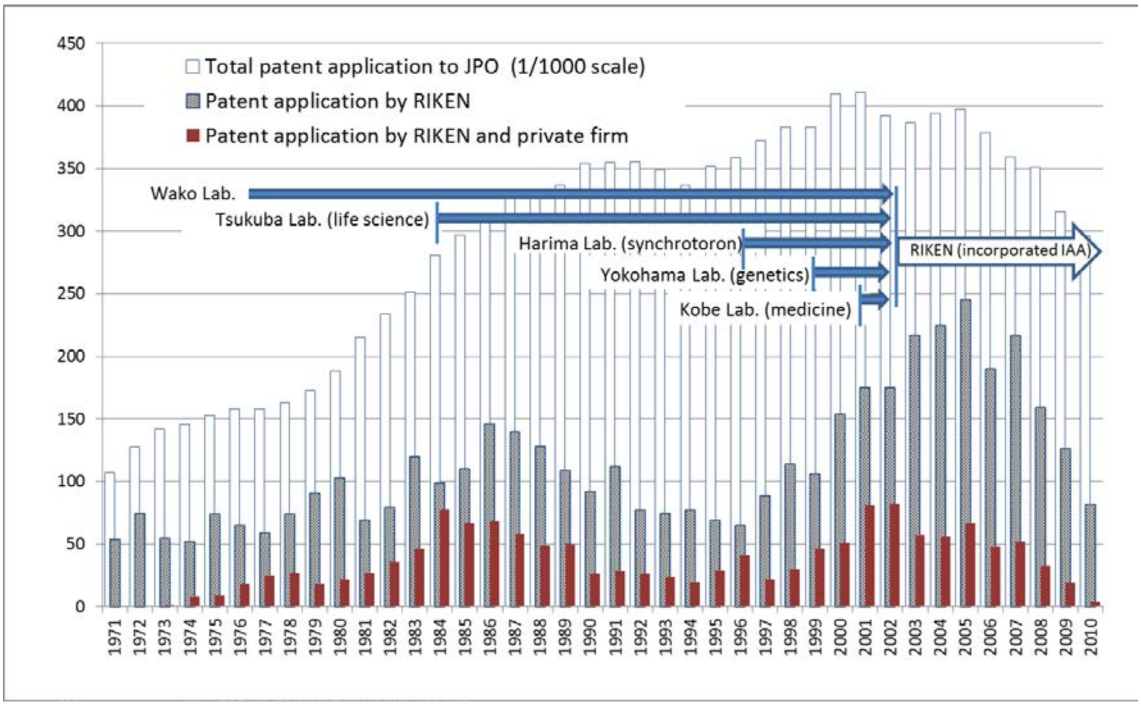

Figure 3. Trends in JAXA's patent applications

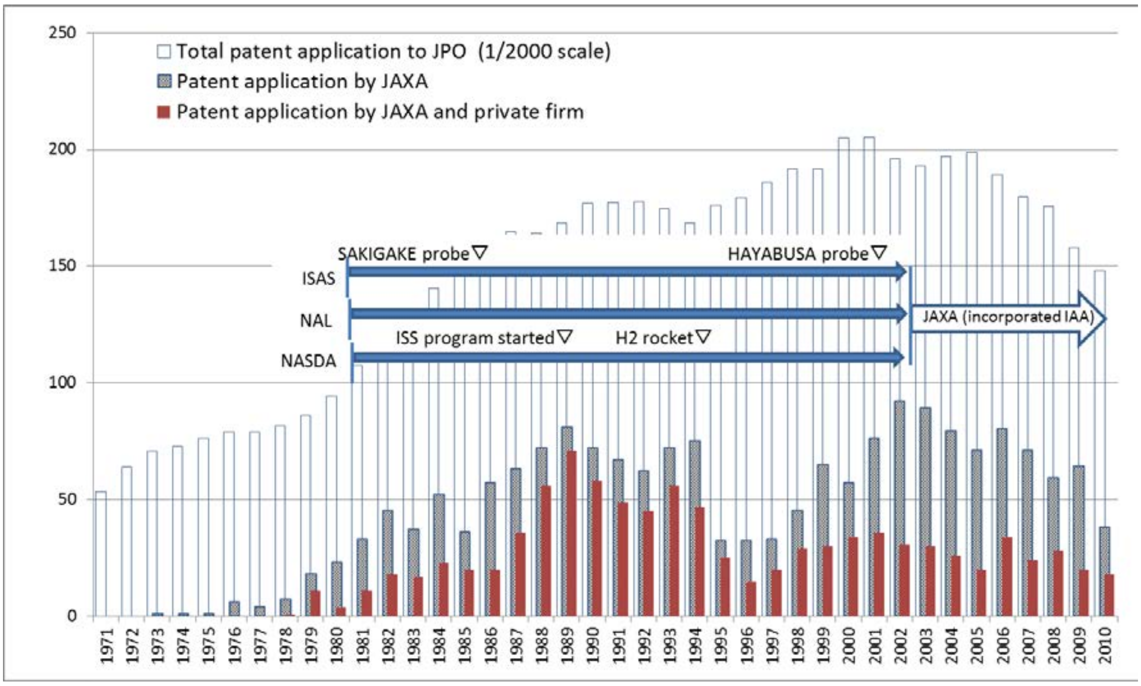

Figure 4. Trends in patent applications by universities in Japan

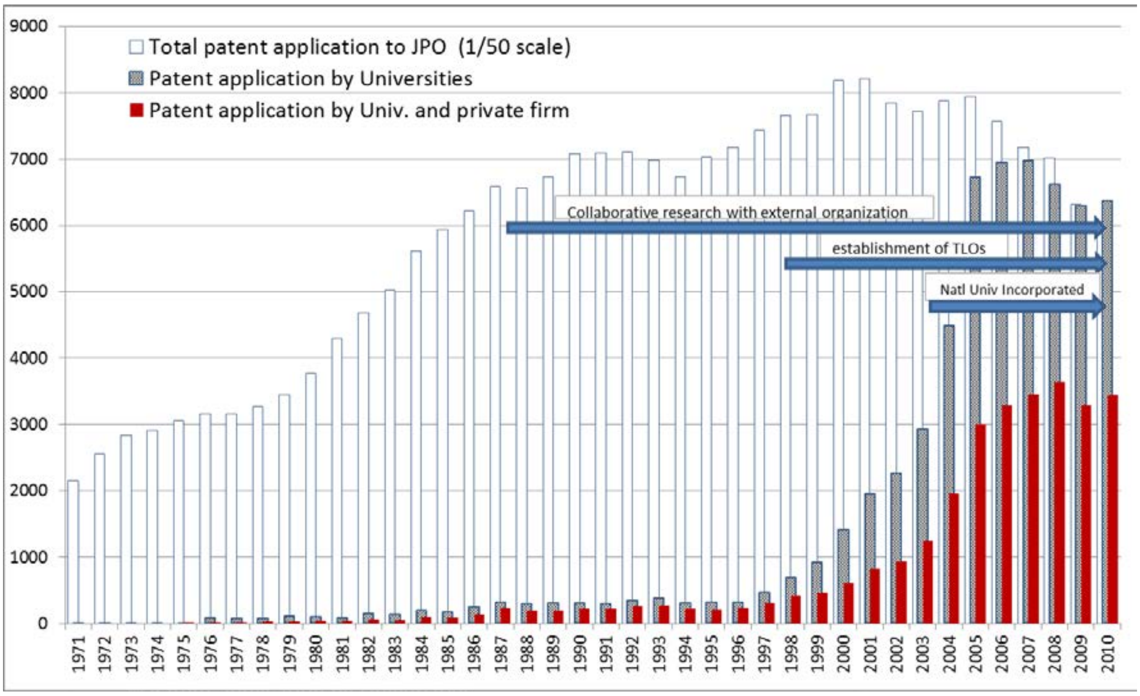

Figure 5. Average performance measures by organization and collaboration structure

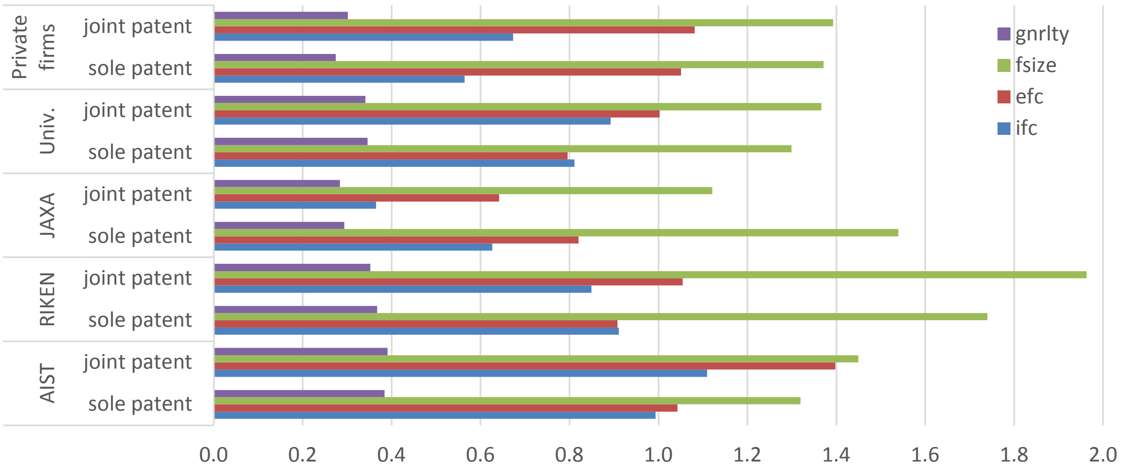

Figure 6. Average input measures by organizations and collaboration structure

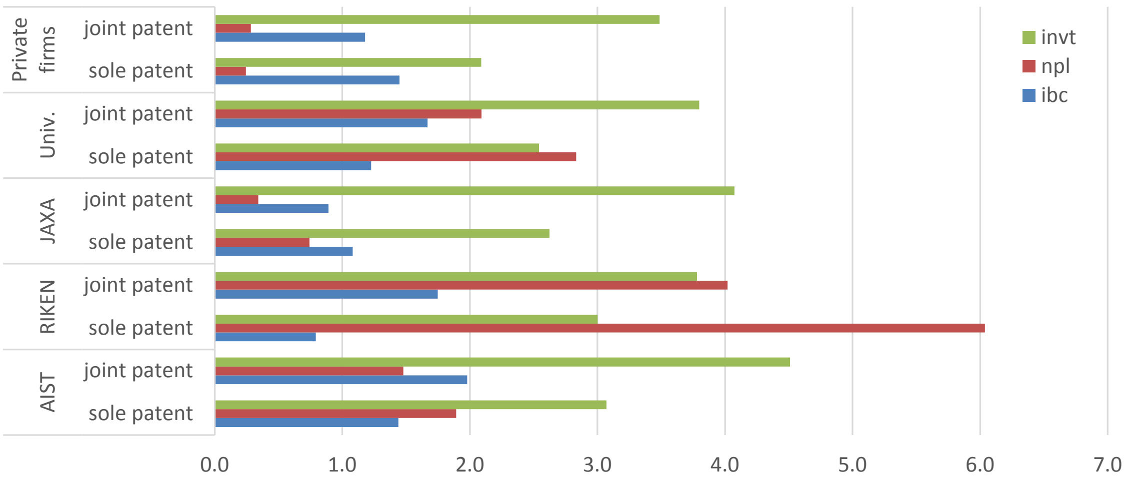

Figure 7. Percentage of joint patents by ITC sector

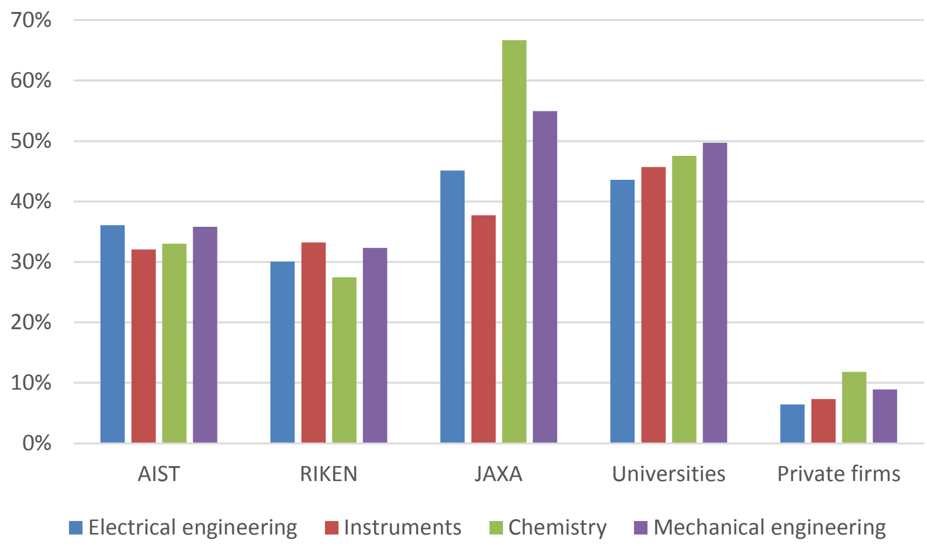

Figure 8. Changes of percentage of joint patent

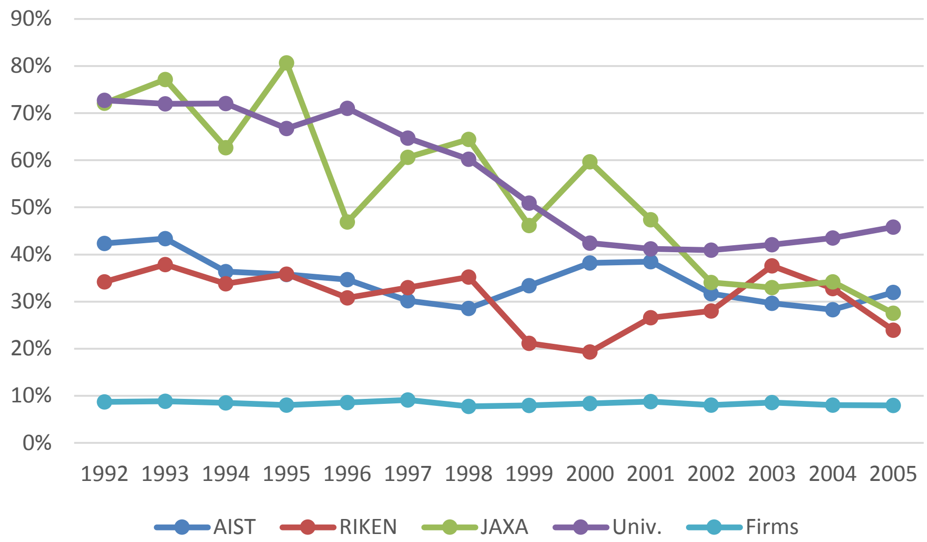

Table 1. Basic statistics and correlation coefficients

	Explanation	variable	Obs.	Mean	S.D.	Min	Max	Correlation coefficient (1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	Inventor frwd citations	ifc	77,975	0.716	2.944	0	343	1						
(2)	Examiner frwd citations	efc	77,975	1.017	1.849	0	57	0.312	1					
(3)	Family size	fsize	77,975	1.369	1.143	1	27	0.084	0.136	1				
(4)	Generality	gnrlty	33,228	0.316	0.273	0	0.908	0.140	0.148	0.039	1			
(5)	Inventor bkwd citations	ibc	77,975	1.441	3.955	0	210	0.116	0.046	0.040	0.028	1		
(6)	Science linkage	npl	77,975	1.190	4.320	0	220	0.031	-0.027	0.081	0.048	0.101	1	
(7)	No. of inventors	invt	77,975	2.674	1.766	1	22	0.052	0.063	0.072	0.078	0.053	0.091	1

Table 2. Estimation results

explanation	variable	(1) NB ifc	(2) NB efc	(3) Poisson fsize	(4) OLS gnrlty
AIST	dum_aist	0.608***	0.017	-0.089***	0.070***
		(0.038)	(0.029)	(0.016)	(0.007)
RIKEN	dum_riken	0.538***	0.012	0.199***	0.055***
		(0.084)	(0.064)	(0.030)	(0.014)
JAXA	dum_jaxa	0.036	-0.248**	0.071	0.052**
		(0.150)	(0.111)	(0.056)	(0.026)
Univ.	dum_univ	0.439***	0.030	-0.042***	0.068***
		(0.039)	(0.028)	(0.015)	(0.007)
Joint patent	joint_pat	0.150***	-0.010	-0.021	0.017**
		(0.039)	(0.028)	(0.015)	(0.007)
After 2001	aft2001	0.276***	-0.120***	0.097***	-0.020***
		(0.023)	(0.016)	(0.009)	(0.004)
	dum_aist * joint_pat	-0.207***	0.152***	0.071***	-0.019*
		(0.057)	(0.042)	(0.023)	(0.010)
	dum_riken * joint_pat	-0.388***	0.057	0.117***	-0.028
PRI x Joint patent		(0.118)	(0.089)	(0.041)	(0.021)
interaction term	dum_jaxa * joint_pat	-0.659***	-0.315**	-0.308***	-0.048
		(0.169)	(0.126)	(0.064)	(0.030)
	dum_univ * joint_pat	-0.184***	0.107***	0.031	-0.030***
		(0.048)	(0.035)	(0.019)	(0.009)
	dum_aist * aft2001	-0.299***	0.047	-0.076***	-0.004
		(0.046)	(0.034)	(0.019)	(0.008)
	dum_riken * aft2001	-0.115	0.058	-0.175***	0.025
PRI x After2001		(0.104)	(0.081)	(0.037)	(0.019)
interaction term	dum_jaxa * aft2001	0.106	0.105	-0.002	-0.032
		(0.165)	(0.124)	(0.062)	(0.030)
	dum_univ * aft2001	-0.266***	-0.270***	-0.161***	-0.017**
		(0.041)	(0.030)	(0.016)	(0.007)
Number of inventors	ln_invt	0.223***	0.197***	0.102***	0.010***
		(0.014)	(0.010)	(0.005)	(0.003)
Inventor bkwd citation	ln_ibc	0.313***	0.156***	0.044***	0.010***
		(0.012)	(0.009)	(0.005)	(0.002)
Science linkage	ln_npl	0.162***	0.049***	0.055***	0.005**
		(0.013)	(0.010)	(0.005)	(0.003)
	Constant	-1.000***	-0.139***	0.200***	0.227***
		(0.034)	(0.025)	(0.013)	(0.006)
Technology field control	itc2 - itc35	Yes	Yes	Yes	Yes
	Observations	77975	77975	77975	33228
	(Pseudo) R-Squared	0.02	0.02	0.01	0.08
	Log Likelihood	-82392.87	-106209.43	-104759.85	

Standard errors in parentheses, * significant at 10%; ** significant at 5%; *** significant at 1%

Table A1. Significance levels of difference between PRIs' or universities' joint patents and firms' joint patents.

	Before 2000				After 2001			
	ifc	efc	fsize	gnrlty	ifc	efc	fsize	gnrlty
AIST's joint patents vs. firms' joint patents	+ + +	+ + +	− −	+ + +	+	+ +	− − −	+ +
RIKEN's joint patents vs. firms' joint patents			+ + +				+ + +	
JAXA's joint patents vs. firms' joint patents	− − −	− − −	− − −		−	− − −	− − −	−
Univ's joint patents vs. firms' joint patents	+ + +	+ +	− − −	+ + +		− −	− − −	

* Number of ＋ or － means significance, ＋: significant at 10%, ＋＋: significant at 5%, ＋＋＋: significant at 1%

** ＋ or - means sign of coefficient