Chapter 25

PATENT STATISTICS AS AN INNOVATION INDICATOR

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Abstract

This chapter summarizes the basic characteristics of patent data as an innovation indicator and reviews some of the recent research using patent data, focusing on major developments since Griliches in 1990 [Griliches, Z. (1990). "Patent statistics as economic indicators: A survey". Journal of Economic Literature 28, 1661–1707]. The first notable development is the availability of patent data on an increasingly global scale and the accompanying global spread of research using patent data. The availability of global patent data has increased the value of patent information in a number of ways. The second notable development is the significant expansion of research using citation information as well as better understanding of its nature. Citation information has been found to provide very useful information on the value of patents, although backward citation as a measure of information flow is found to be more controversial. The third major development is the extensive implementation of surveys such as the "innovation survey" of firms and the inventor survey. They have deepened our understanding of the usefulness and the constraints of bibliographic indicators based on patent. The forth development is better understanding of the nature of the patent system and the reformulation of patent data, a good example of which is the development of patent family data, based on priority information.

Keywords

patent, innovation, invention, R&D, citation, spillover

JEL classification: O31, O34, O33

1. Introduction

Lord Kelvin once wrote, "When you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."[1] While innovation is considered to be the engine of economic growth, measuring innovation is not easy, and our knowledge on innovation remains unsatisfactory. Various attempts have been made to measure innovation. For instance, asking experts in their respective fields to identify major innovations and count them can be very informative and interesting. However, it is subjective and difficult to provide an overall picture of innovation in a continuous manner. R&D expenditure is often used as a proxy for innovation or technological progress. However, expenditure is an input for R&D rather than an output of R&D, which should be innovation. Another candidate is total factor productivity or TFP but again, TFP is affected by factors other than innovation, and it has its own measurement problems, such as its procyclicality and difficulty in obtaining a good price index, particularly for goods with fast quality change or services.

Recently, patent information is increasingly used to analyze innovation and the innovation process, and patent statistics are increasingly used as a measure of innovation. As a matter of fact, patents have been the only source of rich information on new technology, which is screened in a systematic manner by using a considerable amount of resources by governments over a long period of time. The reasons for the increasing use of patent data in recent years are twofold. First, a patent database for the analysis of innovation has been developed. The seminal one is, of course, the National Bureau of Economic Research (NBER) patent database. In addition, similar databases have been constructed by the OECD, European Patent Office (EPO), and Institute of Intellectual Property (IIP) in Japan. Patent data and information, generated by patent offices through their daily operations, have been used by companies to monitor the technological developments and patenting activities of rivals and other firms. But they are extremely difficult and resource consuming to use for statistical analysis because of their sheer size and not statistics-friendly way of storing them. Without the development of these databases, it was very difficult, if not impossible, to use patent data for statistical analysis.

Second, closely related to the first factor, high-quality computers and software became widely available. Today, wherever you are, one can download the NBER database and conduct sophisticated statistical analysis with the help of software one can buy off the shelf.

With this background, and the increasing interest in innovation and technological change by economists, management scholars, and policy makers, it is said that research papers that use patent statistics, have been increasing at a faster rate than patents themselves, which have increased very rapidly (in most countries as we will see) in the last several decades. However, patent statistics should be used carefully and wisely as they are not free from problems nor do they correspond perfectly to innovation. They are affected by the idiosyncratic features of a particular patent system of a nation at a given point in time. It might not be easy to match other economic data. However, if used carefully and wisely, it will lead us to new insights into innovation.

While the detailed explanation of technology itself is in the main text of the patent document, most of the information economists find useful for innovation research is included on the front page of patent

[1] Kelvin, Popular Lectures and Addresses (1891–1894, 3 volumes) vol. 1, "Electrical Units of Measurement", 1883-05-03.

documents, although the exact content varies across patent offices and over time. It usually includes the inventor's name and address, the applicant's (or in the case of the United States Patent and Trademark Office, the assignee's) name and address, dates such as the priority date, application date and grant date, and technology classes, usually based on International Patent Classification (IPC). It can also include the references to patents and nonpatent documents such as academic papers. Using this bibliographic information, various research on innovation is possible, part of which will be reviewed in the following sections of this chapter.

However, caveats are in order. Not all patents represent innovation, nor are all innovations patented. First, the value of patents is highly skewed, as there are a small number of highly valuable patents and a large number of patents with little value. Scherer and Harhoff (2000) showed that about 10% of the most valuable patents account for more than 80% of the value of all the patents, based on their survey of German patents. According to the Japan Patent Office (JPO) survey, more than 60% of patents are neither used internally nor licensed out. Firms often use patents strategically; for instance, take out patents on inventions simply to block other firms' patents or to deter entry.

Second, there are many inventions that are not patented. In order for an invention to be granted a patent, an invention has to satisfy certain criteria, in particular, novelty, nonobviousness (or inventive step), and industrial usefulness. Those criteria and their interpretation differ over time and across countries. For instance, chemical compounds were not patentable in many countries, even in Europe, in the 1950s and 1960s. In developing countries, useful innovations might not have satisfied these criteria even in more recent years, or inventors might not have bothered to apply for patents, given the unsatisfactory enforcement of patent rights. In addition, firms may deliberately choose not to patent their inventions, since patent systems require their disclosure. If firms believe that they can protect their inventions by other means such as making it a trade secret, they might decide not to patent. Perhaps reflecting this consideration, a larger part of process innovation is not patented compared to product innovation.[2] Still patent information is the most valuable source of information, but users should keep in mind that it is not free from various types of noises and biases.

This chapter intends to summarize the basic characteristics of patent data, and some of the research which uses patent data. Griliches (1990), one of the greatest contributors to this area of research, wrote a well-known paper on this subject almost two decades ago. In this paper, he compared patent statistics to the food at a Catskills Resort, "terrible food, and the portions are small." This chapter reports the progress economists have made, things we have learned since then about how to enjoy this food. This paper is organized as follows: Section 2 explains the information that is included in patent documents; Section 3 discusses inventors and applicants (or assignees); Section 4 introduces the concept of a "patent family," which is increasingly used for international comparison as well as for taking into account continuing applications; Section 5 reviews the role of patent information to understand the innovation activities; Section 6 summarizes various attempts to measure the value of patents; Section 7 explains how citation information contained in patent documents, "paper trace," can be used to track down knowledge spillover; and Section 8 concludes the chapter and suggests possible future research areas.

[2] See Section 5.2 for more details.

2. Information in the patent documents

2.1. Scope of patent information and its relation with the patent system

Patent documents provide a rich set of information on the invention and the patent, and are structured as follows: the bibliographic information, the abstract of the invention, the claims, the description of the invention, and the drawings and their description (see OECD, 2008 for a detailed guide to patent documents). The bibliographic information is the set of information useful for identifying the invention and the patent. As shown in Table 1, the patent database developed for academic research (NBER patent database, PATSTAT, and the patent database of IIP in Japan) use mainly bibliographic information. Table 1 categorizes the information into eight categories: (1) application, including title, abstract and technology class; (2) priority, continuing applications, and family; (3) publication; (4) examination request; (5) grant, including technology class; (6) applicant and assignee; (7) inventor; and (8) citation relationship.

It is important to note that there exist significant differences in the patent systems of different countries, which significantly affects the scope and nature of patent information generated as well as its relation to R&D. One major difference is while there is an examination request system in Europe and Japan, there is no such system in the United States where all applications are examined. As a result, in Europe and Japan, a firm can apply for a patent but still has the option to request a patent examination. Since the application fee is low,[3] the examination request system tends to encourage firms to apply for a large number of patents. In addition, there can be a long time lag between patent applications and grants under the patent examination system, since a firm can defer the request for a significant period (within 7 years in Germany and within 3 years in Japan from the application date, and within 6 months from the publication of the search report to the EPO). As a result, the patent grant information can be a poor indicator of the recent inventive activities in these countries.

The second major related difference is that all patent applications are automatically disclosed in Europe and Japan but not in the United States (disclosure of patent applications was introduced in 1999, but only partially). As a result, while the published patent applications provide comprehensive information on the inventive activities in Europe and Japan, they do not in the United States. Thus, as an indicator of the inventive activities, patent grant information is commonly used in the United States while patent application information is used in Europe and Japan. Since not all patent applications are requested for patent examination (66% in Japan and 95% in the EPO in 2007)[4] and only a part of them result in granted patents (49% in Japan and 51% in the EPO), it is important to note that only a part of applications (only around one-third in Japan) will be granted patents under the examination request system.

[3] It is 150 US dollars per application in Japan with an exchange rate of 1$ = 100 Yen and it is 100 ECU for electronic filing in the case of EPO at the time of writing (early 2009).

[4] Both examination rates and grant rates are based on the Trilateral Statistical Report (2007). The examination rate is "the proportion of those applications for which the period to file a request for examination expired in the reporting year that resulted in a request for examination up to and including the reporting year." The grant rate is the number of applications that were granted during the reporting period, divided by the number of disposals in that period. The examination request rate for the German Patent Office is much lower than that for the EPO (around 60%).

Table 1
Comparison of patent information available from three databases for research

Database		NBER US patent data files	PATSTAT for 172 patent offices	IIP patent data on the Japanese patents
(1) Application, including title, abstract and technology class	Application number	–	0	0
	Application date	0	0	0
	Number of claims	–	X	0
	IPC	–	All	Primary
	National technology class	–	All	–
	Other technology classification	–	–	0
	Application authority	–	0	–
	Application title	–	0	X
	Application abstract	–	0	X
(2) Priority, continuing applications, and family	International application number	X	0	X
	Priority application number	X	0	X
	Parent application number	X	0	X
	Continuation type	X	0	X
	Family information	–	0	X
(3) Publication	Publication number	–	0	X
	Publication date	–	0	X
(4) Examination request	Examination request	–	X	0
(5) Grant, including technology class	Grant number	0	0	0
	Grant date	0	0	0
	Expire date	X	X	0
	Number of claims	0	X	0
	IPC	Primary	X	Primary
	National technology class	Primary	X	–
	Other technological classification	0	–	0
(6) Applicant and assignee (patent right holder)	Applicant name	X	0	0
	Applicant name (standardized)	X	0	X
	Applicant address	X	0	X
	Country/states of applicant	X	0	0
	Type of applicant	X	–	0
	Assignee name	0	X	0
	Assignee name (standardized)	0	X	X

	Assignee address	X	X	X
	Country/states of assignee	X	X	X
	Type of assignee	0	X	X
(7) Inventor	Inventor name	0	0	X
	Inventor address	0	0	X
	Country/states of inventor resider	0	0	X
(8) Citation relationship	Citing patent number	0	0	0
	Cited patent number	0	0	0
	Citation type (examiner/ inventor)	X	0	0
	Nonpatent literature citations	X	0	X
(9) URL		http://www.nber.org/patents/	http://www.epo.org/patents/patent-information/raw-data/test/product-14-24.html	http://www.iip.or.jp/

–, Not applicable; X, not available.

The third major difference exists in the source of disclosure in patent documents with respect to prior art. In the United States, applicants must disclose all prior art to the patent office, under the Code of Federal Regulations on Patents, Trademarks, and Copyrights. The failure of disclosure can result in the loss of the patenting right.[5] As a result, US patent applications are accompanied with a significant number of references cited by applicants. There is also a concern that the applicants supply a large number of documents strategically. According to the USPTO, "For example, some applicants send a very large number of documents to the examiner, without identifying why they have been submitted, thus tending to obscure the most relevant information. Additionally, some applicants send very long documents without pointing out what part of the document makes it relevant to the claimed invention."[6] In the United States, examiners add references, amounting to 40% of all citations (see Section 7.1 for more details).[7]

In the case of the EPO, the disclosure of prior literature is not obligatory[8] and examiners are the dominant source of references. Most citations in the search report are identified by the examiners (according to Criscuolo and Verspagen, 2008, the share of inventor citations is only 9% in 2000). Similarly, in Japan, while there is a general obligation for disclosing related patents (Article 36 on patent applications),[9] which was recently introduced,[10] the penalty for failing to do so is not explicitly defined. In addition, the timing of the public disclosure of the cited documents also differs across offices. In both the United States and Japan, patent grant documents provide a complete list of the references, while in the EPO the search report provides a list of references. In Japan, the patent application documents also list the references disclosed by the inventors, and the patent office also discloses the prior art used for the rejection of the patentability of the invention requested for patent examination.

In light of these differences, we would like to briefly compare three databases (Table 1). The pioneering NBER database (see Hall et al., 2002 for a full description) is entirely based on the US patent grant data. It has comprehensive information on the citation relationship among the US patents. On the other hand, it has no information on priority and continuing applications and on the technology classification by IPC. In addition, it does not have information on co-ownership, perhaps due to the

[5] § 1.56 (Duty to disclose information material to patentability) states that, "each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. . . . no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct." See http://www.uspto.gov/web/offices/pac/mpep/documents/appxr.htm.

[6] See *Proposed Rule Changes to Focus the Patent Process in the 21st Century of USPTO* (http://www.uspto.gov/web/offices/pac/dapp/opla/presentation/focuspp.html).

[7] Examiner citations have been identified by * since 2001.

[8] Rule 27 (Content of the Description) (1) b only says, "The description shall indicate the background art which, as far as known to the applicant, can be regarded as useful for understanding the invention, for drawing up the European search report and for the examination, and, preferably, cite the documents reflecting such art." See http://www.epo.org/patents/law/legal-texts/html/epc/1973/e/rciii_ii.html.

[9] Article 36 (4) states, "The description of the detailed explanation of the invention has to satisfy the following: . . .. (ii) Where at the time of filing of the patent application the person requesting the grant of a patent has knowledge of any invention(s) . . . related to the said invention, that has been known to the public through publication, the description shall provide the source of the information concerning the invention(s), such as the name of the publication and others." See http://www.cas.go.jp/jp/seisaku/hourei/data/PA.pdf.

[10] It became effective as of September 1, 2002.

small percentage of co-ownership among the US firms (see Section 3 for further discussions). The revision of the NBER patent database, which is under way, is expected to address these issues.

The EPO Worldwide Patent Statistical Database (PATSTAT) developed by the EPO covers 172 countries, so it has a global scope. It covers more than 53 million national or regional patent records and 7 million utility model patent records. PATSTAT is based on the patent application data, but it also covers the information on the publication and the grant. Unlike the NBER patent database, it also covers continuing applications and priority information, the patent family data, and both the national and IPC and co-ownership. It also has the abstracts of applications, and both patent and nonpatent literature as citation documents. On the other hand, it does not have information on patent examination requests or the number of claims.[11] The IIP[12] database is based on patent processing documents disclosed by the JPO (Seiri-Hyoujyunka database of the JPO). Goto and Motohashi (2007) provide a detailed explanation of the database. Its unique features are that it has information on examination requests as well as expiration (or renewal) dates and information on assignees, separately from applicants. Furthermore, it has the original information described in Japanese, including Chinese characters, and is now under revision for the inclusion of inventor information and so forth.

2.2. Patent applications around the world

The patent application statistics is reported by the World Intellectual Property Organization (WIPO) under the publication called "World Patent Report."[13] Figures 1 and 2 show the trend of top 10 countries (region) by patent office. In 2006, the USPTO accepted the largest number of patent applications, which is followed by the JPO. The JPO had kept its top position for years, but it was surpassed by the USPTO due to its slowdown of patent applications since the 1990s. In the 1970s, a slowdown of patent grant was observed in the United States. Whether this was due to declining research productivity became a major concern (Evenson, 1993; Griliches, 1990). However, the number of patent applications started to increase in the early 1980s. This timing coincides with the establishment of CAFC (Court of Appeals of the Federal Circuit), one of the central events in the move toward propatent policy in the United States. However, Kortum and Lerner (1999) conclude that this is explained more by changes in the R&D management. Hall and Ziedonis (2001) reconsider the findings of Kortum and Lerner (1999), and contend that the increase of patents was due to changes in patent management, rather than R&D management. In contrast, patent applications in Japan have been stagnated since the 1990s. An introduction of multiple claim system in 1989 partly explains this trend (Goto and Motohashi, 2007). Another factor may be changes in IPR policy at firm, such as introducing more stringent rule and selection criteria in patent application decision (Motohashi, 2004) In addition, JPO has tried to persuade industry to apply patents more selectively due to the concerns over the overwhelming number of applications and the delay of examinations.

Recently, there has been a sharp increase of patent applications to Chinese patent office from the world, and it jumped up to the third position in the world in 2006. The current patent system in China was established in 1985, and series of reforms have been introduced. Particularly, after the second

[11] See http://forums.epo.org/epo-worldwide-patent-statistical-database/.
[12] Institute of Intellectual Property (Japan). To use this database, see, http://www.iip.or.jp/e/index.html.
[13] The annual patent statistics in the world can be found in the WIPO web site (http://www.wipo.int/ipstats/en/statistics/patents/).

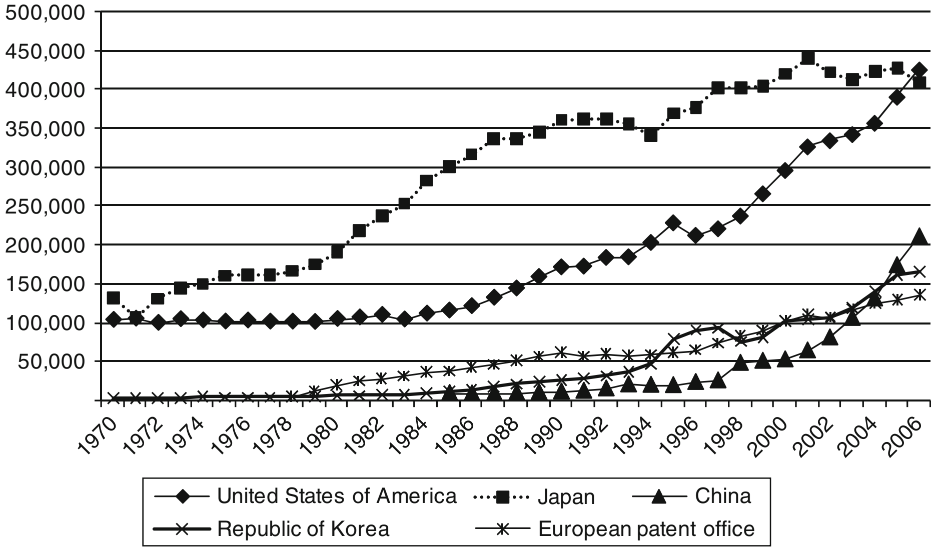

Figure 1. Patent applications at offices around the world (1).

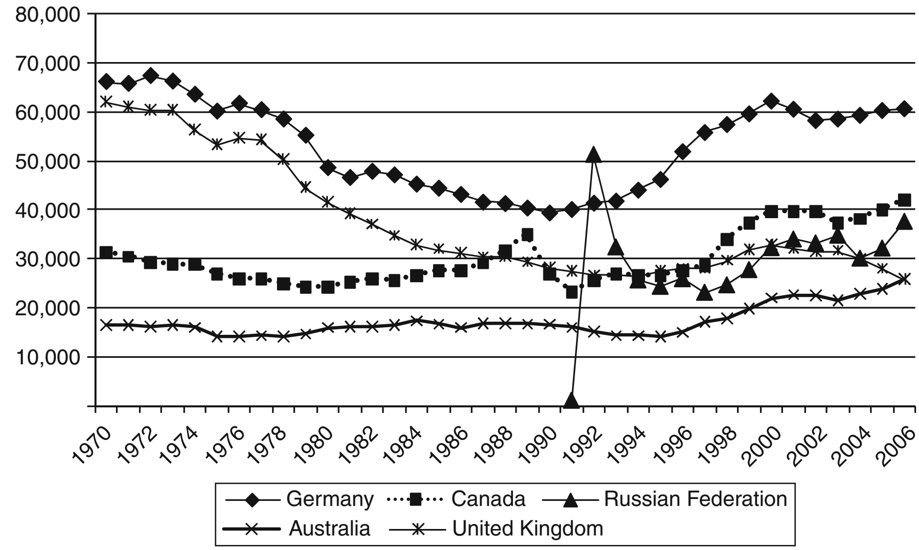

Figure 2. Patent applications at offices around the world (2).

amendment to China's patent law in 2000, conducted to prepare for China's accession to WTO in 2001, both domestic and international inventors have become to rely on the protection of intellectual property system in China. The fourth position is occupied by Korea. Patent application to Korea is also increasing rapidly although not to the extent of that to China.

The number of EPO patent applications is the fifth, following that of Korea. Under the European Patent Convention (EPC), an inventor can apply to EPO, designating the specific countries where she wants her patent rights to be effective. Patent examinations are provided by the EPO, while patent registration is processed by individual country under each country's specific regulation. For European countries, a patent can be applied either though this system or directly to patent office in each country. Therefore, patent statistics for Germany and the United Kingdom are separately provided in Figure 2. It is found that the numbers for these two countries have not increased even in the long run, presumably due to increasing number of EPO filings. The rest of top 10 counties are Canada, Russian Federation, and Australia.

In general, patent applications to emerging economies are increasing, while those to developed countries are stagnated, except in the United States. Among the top 20 countries in 2006, two large emerging economies, China and India, become to be a hot spot of patent applications (WIPO, 2008). The annual average growth rate from 2000 to 2006 is 26.3% and 23.6% for China and India,[14] respectively, followed by Hong Kong (8.6%), Korea (8.5%), and the United States (6.3%).

Intensification of patenting activities by both multinational firms and domestic firms led to the global increase of the patenting. A surge in patent filing in emerging economies are driven substantially by multinationals in developed countries, and the share of patent filing by nonresidents have increased to 43.6% in 2006 from 35.7% in 1995 (WIPO, 2008). Figure 3 shows the number of patent filing by origin in 2000 and 2006, instead of the location of patent office. The largest amount comes from Japan,

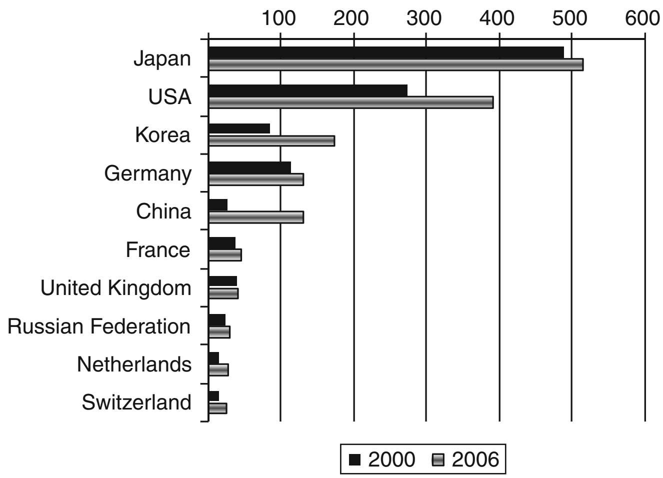

Figure 3. Number of patent applications by applicant origin.

[14] 2000–2005 for India.

followed by the United States and Korea. This number increased substantially in Korea and China from 2000 to 2006, so that not only multinational's patenting but also domestic players have contributed to growing number of patent filing in these countries.

3. Inventors and patent owners

3.1. Inventor team size and types of owners

From patent document, we can identify the names and addresses of inventors and applicants. The applicant for a patent holds the legal right of the patent, and it is usually the case that the applicant is the one who provides resources (employee inventors and research funds) to conduct the R&D project that led to the patent. The US patent document provides information on the assignees, instead of applicants. An important point to note is that the inventor's address in the patent documents is often his business address but sometimes it can be his home address. Even if it is his business address, it can be the address of the headquarters of the firm and not that of the business unit to which the inventor belongs. Therefore, the inventor's address does not necessarily identify the exact geographical location where the invention is made.[15] It does not identify the organizational affiliation of an inventor either for the same reasons.

The patent-based information on inventors can be used to measure the size of the research team and a broad geographic location of inventors, even though the aforementioned problem remains. Figure 4A–C shows the distribution of the team size of inventors for triadic patents for the United States, Germany, and Japan for the period from 2000 to 2005 by three types of ownership structure. It is based on the information from the US patent in the triadic patent families for which the US patent has been granted and the Japanese and the EPO patents have been applied.[16] The distributions are very similar across the three countries. If we start focusing on the distribution of the team size in cases where the patent is owned by a single domestic entity, the single inventor invention is most frequent but accounts for only around one-third of the patents in the three countries (29% in Japan, 26% in the United States, and 27% in Germany). The average team size is 2.78 for Japan, 2.84 for the United States, and 2.93 for Germany in the case of a single domestic applicant. Thus, an invention is very much a product of teamwork. The frequency of patents declines with the size of the team and patents with five or less inventors account for 90% of all patents.

As pointed out by Jones (2009), there has been an increase of team size in the United States, together with an increase in the age at which the first invention is made, and a decline in the probability of a change in specialization over the career of inventors for the last two or three decades. The average team size was 1.7 in 1975 and rose to 2.2 in 1999. This may suggest that the broad accumulation of knowledge for an invention is becoming increasingly important. Significant differences exist in the team size across sectors. According to Figure 5, four to five inventors on average work together for drug inventions, while less than 2.5 inventors on average collaborate for inventions of apparel and textile, in all three countries. The distribution across sectors is very similar across three countries.

[15] Besides, US patent documents do not provide street address.

[16] Each national data in Figures 4–6 and in Table 2 covers the patents which have at least one domestic inventor and at least one domestic applicant. If there are more than a single US patent in a patent family, we use the patent with the earliest application date. See Section 4 for more details of a patent family.

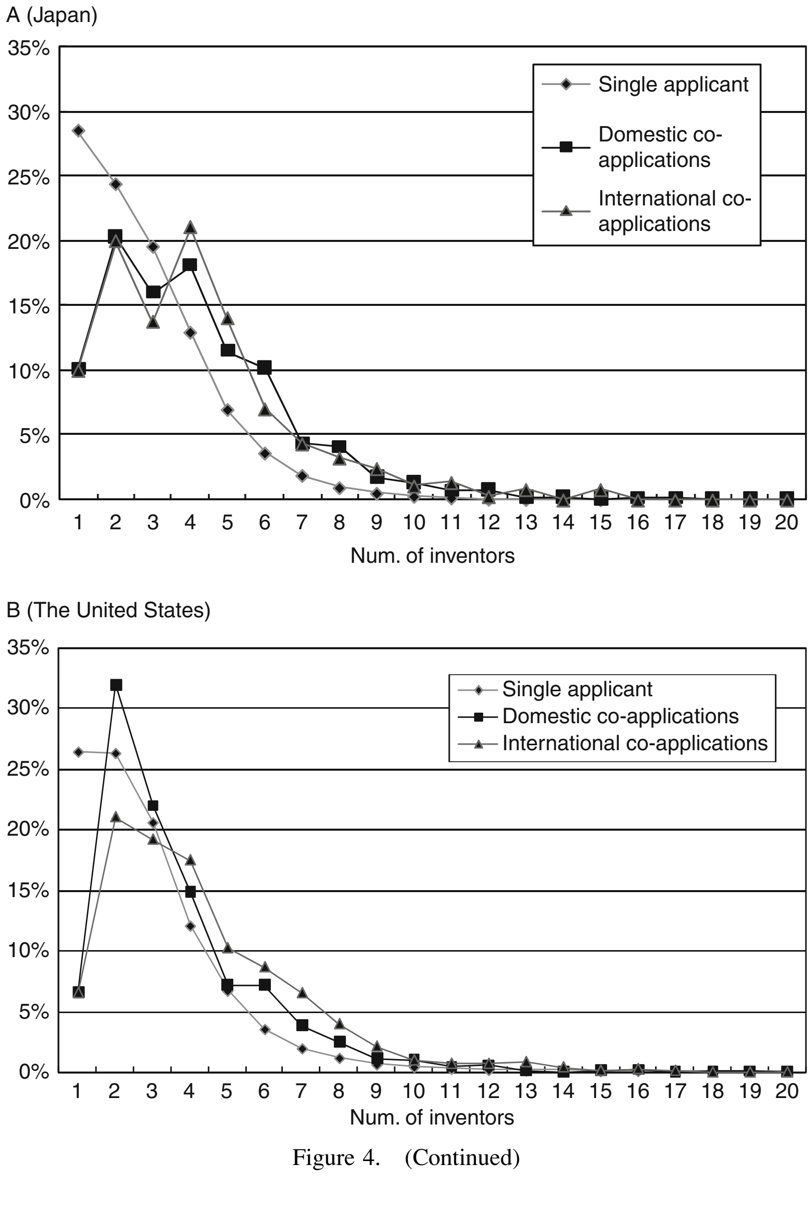

Figure 4. (Continued)

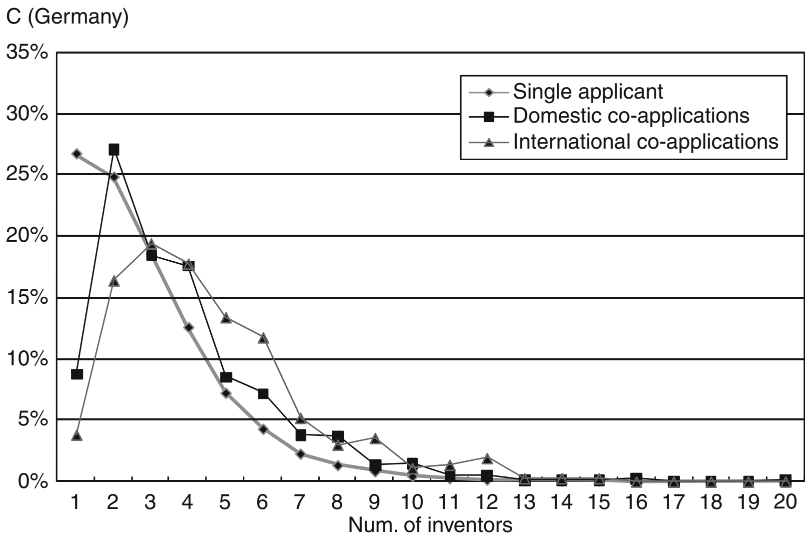

Figure 4. (A) Distribution of inventors, 2000–2005 (Japan), triadic patents. [*Note*: Patents with at least one domestic inventor and applicant for each county for Parts A–C.] (B) Distribution of inventors, 2000–2005 (the United States), triadic patents. (C) Distribution of inventors, 2000–2005 (Germany), triadic patents.

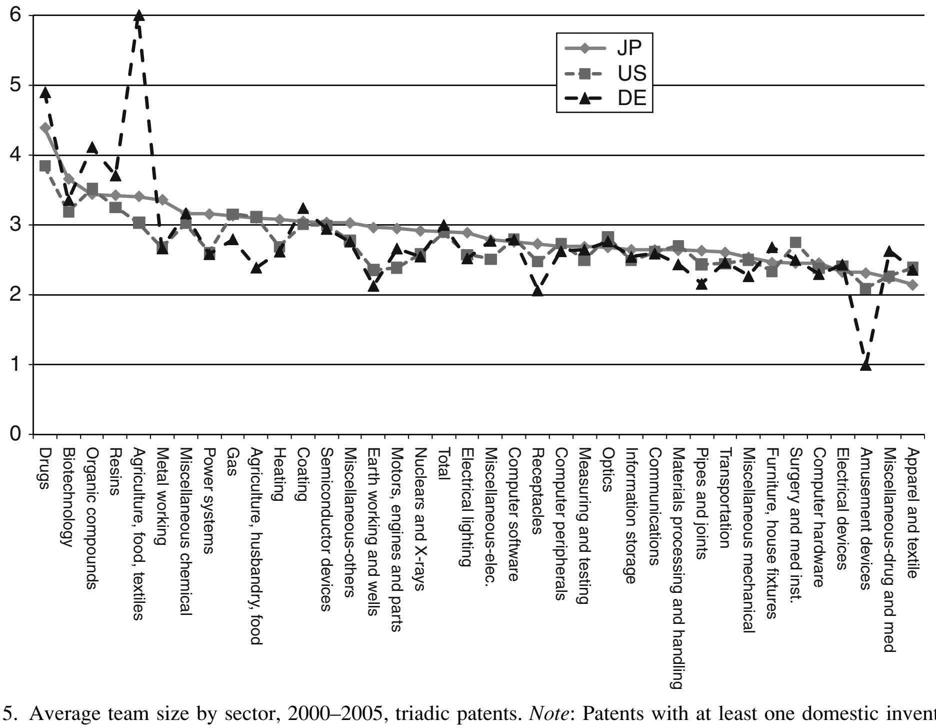

Figure 5. Average team size by sector, 2000–2005, triadic patents. *Note*: Patents with at least one domestic inventor and applicant for each county.

The patent information on inventors can be used to understand how the invention process is internationalized, by examining whether inventors resident in different nations are involved in one patent, that is, whether an international coinvention is involved. Figure 6 shows the evolution of the share of international coinventions since the 1980s, based on triadic patents with at least one domestic inventor and one domestic applicant, which shows that the extent of international coinvention has significantly increased over the years for national firms. In the United States only around 2.2% of the inventions involved international coinventions in the 1980s, but increased to around 8.3% in the 2000s. It also varies significantly among these five countries. In the case of Japan, only 1.5% of the inventions involve international coinventions. On the other hand, in the case of the United Kingdom, more than 12% of them involve international coinventions.[17]

While team work is the dominant form of invention, single ownership is the dominant ownership structure. As shown in the last column of the national tables in Table 2 for triadic patents, more than 90% of the patents are owned by single entities: 91% in Japan, 95% in the United States, and 94% in Germany. International co-ownership is further limited: 0.8% for Japan, 1.6% for the United States, and 1.8% for Germany. As shown in Figure 4, co-ownership is associated with larger team size. The median team size of inventors increases to two for the three countries when there is domestic co-ownership (the average team size is 4.1 for Japan, 3.7 for the United States, and 3.8 for Germany in the case of a domestic co-ownership). International co-ownership further increases the team size, although this is not apparent in the case of Japan (4.2 for Japan, 4.3 for the United States, 4.6 for Germany). In all three countries, international coinventions often accompanies international co-ownership (60% of the international co-ownership cases in Japan and more than 70% of those cases in the United States and

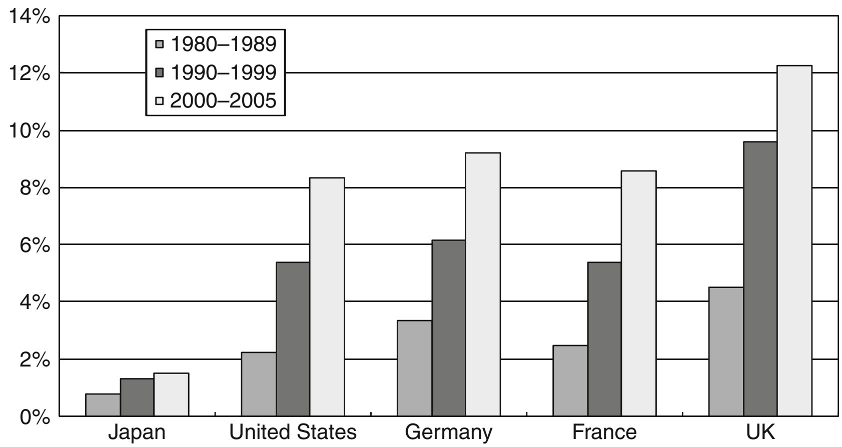

Figure 6. The evolution of the frequency of international coinventions. *Notes* (1): Patents with at least one domestic inventor and applicant for each county. (2) Patents classified by application years.

[17] If we include the inventions with only foreign applicants, the share of international coinventions increases to more than 25% in the United Kingdom.

Germany) according to Table 2. Thus, collaboration across organizations and across borders seems to enable the formation of a larger and heterogeneous research team, which can address a more complex and difficult research task.

If the inventor himself owns a patent, he is usually considered to be an independent inventor. It is well known that they played a major role for the innovation process particularly in the past (see Lamoreaux and Sokoloff, 2005). According to their estimate, the share of patents assigned to corporations was only 18.5% from 1870 to 1871 in the United States. This share has increased significantly over time, while the share of independent inventors has declined in a major way, as R&D organized by firms rose (see Mowery and Rosenberg, 1991). The share of individuals in the US patent grants for triadic patents was at 4.1%, according to Table 3. There is a significant difference between the United States, Europe and Japan. In the case of Japan it was only 1.6% of the triadic patents[18] while it was 7% in Europe.

Table 2
Structure of inventors and owners in Japan, the United States, and Germany

	Single inventor (%)	Domestic coinventions (%)	International coinventions (%)	Total (%)
Japan (2000–2005)				
Single applicant	26.0	64.2	1.0	91.1
Domestic coapplications	0.8	7.2	0.1	8.1
International coapplications	0.1	0.2	0.5	0.8
Total	26.9	71.6	1.5	100.0
United States (2000–2005)				
Single applicant	25.0	62.7	7.0	94.7
Domestic coapplications	0.2	3.3	0.2	3.7
International coapplications	0.1	0.4	1.1	1.6
Total	25.3	66.4	8.3	100.0
Germany (2000–2005)				
Single applicant	25.2	61.4	7.6	94.2
Domestic coapplications	0.4	3.4	0.2	4.0
International coapplications	0.1	0.3	1.4	1.8
Total	25.6	65.2	9.2	100.0

Source: Based on the patent with the earliest priority date in the OECD triadic patent family.

Table 3
Share of applicant types by applicant origin

	Individual (%)	Corporate (%)	Public institute (%)	University (%)
Europe	7.0	90.1	2.2	0.7
Japan	1.6	98.0	0.2	0.2
United States	4.1	92.8	0.7	2.4

[18] The share of individuals in all patents is significantly larger (around twice more than that for triadic patents). In Japan it was 3.4% of patent applications in 2007, while it was 8% of US patent grants in 2008 (based on the reports from national patent offices).

3.2. Co-ownership versus research collaborations

Collaborations for research among different organizations have become an important issue, given the increasing complexity of the R&D process as well as the increasing number of organizations becoming active in research. The bibliographic information in the patent documents, especially the data on coapplications, is available for assessing how widespread the interorganizational collaboration is. However, it has been found to significantly underrepresent the extent of research collaborations, the extent of which depends on the co-ownership rule of a patent system of a country. We might expect that the collaborative research would often result in the sharing of the ownership, so that co-ownership or coapplication of patents is a good indicator of research collaborations. However, the ownership right can be consolidated to the hand of a single firm or it can be transferred even to a third party before the patent application, so that a list of the applicants or assignees often provides only partial information on the parties who provide resources to the invention process. Indeed, according to Hicks and Narin (2000) and Hagedoorn et al. (2003), the intensity of the research alliance among firms has almost no correlation with the frequency of co-ownership of patents, at least in the United States.

The recent inventor surveys in Europe, Japan, and the United States (Giuri et al., 2007; Walsh and Nagaoka, 2009) addressed this question directly by asking inventors whether there was an external coinventor who belonged to a different organization, as well as whether there was a formal or informal collaboration other than coinventions for the underlying research of the patent. As shown in Table 4, 12–15% of patents involve coinventions of the inventors belonging to different organizations (the second row for external coinvention in Table 4) in the three countries and region. Thus, the incidence that an inventor, belonging to an external organization, participates in the research is quite similar and high across the three countries and region. However, the incidence of co-ownership is substantially lower and varies a lot: less than 2% in the United States, 6% in the European Union, and 10% in Japan for the same samples (first row of Table 4). The third row of Table 4 also shows the incidence of formal or informal collaborations for research with an external organization, short of coinventions. The level of the collaborations in this definition is more than 20% (close to 30% in the case of Japan). Thus, it is clear that co-ownership of a patent underestimates the actual extent of these broader research collaborations significantly and by different degrees, depending on the countries and region.

The above results might raise the following two questions: In the United States, why co-ownership is so rare and why the ownership has the tendency of being consolidated to a single firm in all three regions although the extent differs across countries. The answers for these two questions seem to be related.

Table 4
Incidence of coapplications versus that of research collaborations (%)

	EU	United States	Japan
Coapplications based on patent documents	6.1	1.8	10.3
External coinvention	15	12.4	13.2
Research collaborations, which do not involve coinventions	20.5	22.7	28.5

Source: Prepared from Giuri et al. (2007) and Walsh and Nagaoka (2009).

The important reason for the rare use of co-ownership in the United States seems to be its unique legal rule on the right of co-owner. In the United States, a coassignee can license his right to use the invention to a third party without the consent of another coassignee. Thus, the coassigned patent right implies almost complete loss of the control over the use of the invention, unless such restriction is separately agreed with each coassignee. In Japan and in major European countries, a coassigned patent can be licensed only if all coassignees agree, unless otherwise agreed, even though each co-owner can freely employ the invention as in the United States. Thus, the co-ownership defined by the US law does not seem to provide an efficient standard contract, so that it is not used in the United States. Furthermore, co-ownership rights are not preferred in Japan or Europe either, as shown by the fact that coapplications are much less used even in Europe and Japan, relative to the incidence of externally coinvented patents. The reason seems to be the inefficiency of co-ownership under many circumstances, such as free-riding on the development investment for the invention and on the enforcement of the patent right, in addition to the loss of exclusive use. When the invention can be most profitably exploited by a single firm, there is no reason for co-ownership even if the invention is jointly developed.

4. Patent family

4.1. Use of patent family data for international comparison

A patent family is, "the set of patents (or applications) filed in several countries, which are related to each other by one or several common priority filings," according to OECD (2008). The triadic patent family of the OECD is a good example. There are two types of patents in a patent family protecting the same invention. The first type covers the patents applied in different countries. The second type covers the patents generated by applications based on patents applied earlier. We will discuss them in turn.

According to Figure 3, inventors in Japan have been involved with patenting activities most actively in the world. However, as we have already indicated in the previous section, there are limitations and pitfalls in using patent counts as invention counts. In Japan, it was very difficult, if not impossible, to include more than one claim in one application before the 1989 amendment of the patent law. Since the amendment, the average number of claims per patent at the JPO has been increasing but only gradually. In 2007, applications filed at the JPO had 9.8 claims, those filed at the EPO had on average 18 claims, and those at the USPTO had 20.1 claims.[19] Therefore, the number of patent counts at the JPO may overrepresent inventive activities as compared to those at the USPTO or EPO.

In addition, it should be noted that patent applications were not published in the United States until they were granted, before the American Inventors Protection Act of 1999 was enacted.[20] In other countries, all patent applications are published within 18 months of the filling date. In this regard, patent application counts underestimate inventive activities in the United States relative to those of Japan, although the US aggregate application numbers in Figure 1 cover unpublished patent applications too.

[19] Trilateral Statistical Report (2007).

[20] It should be noted that not all application patent are published under AIPA 1999. If a patent applicant will not seek a patent for the same invention outside the United States, that patent information does not have to be disclosed (7% in a recent year).

In order to control for such differences in the patent system, one may want to rely on the patent statistics in one country. For example, using USPTO patent data, one can compare the number of patents by the origin of inventors. However, obviously, such comparison involves “home country bias,” in the sense that the US inventors have home advantage so that they file for more patents in USPTO compared to foreign applicants for a given set of inventions. Dernis and Khan (2004) show that such bias exists by comparing the EPO and the USPTO patent data, then propose to use the OECD triadic patent family database as one of the solutions for international comparison of inventive activities based on patent data. Additional major advantage of the triadic patent family database is that it focuses on higher quality patents, since the cost of filing patents in all of three patent office works as an important screening device and the applicant has additional 1 year to evaluate the quality of his invention for a foreign application. This advantage is important for an analysis of invention performance, given the skewed nature of patent quality.

The OECD triadic patent family database is constructed by using the priority date information of international patent applications to EPO, JPO, and USPTO (granted in the United States). According to the Paris convention or the PCT rule, the priority date (application date of the original application) can be kept for patent applications for another country (or region), when inventions are equivalent. By grouping such identical and related patents applied to or granted by the EPO, JPO, and USPTO into one family, differences in patent systems across countries can be controlled for to a significant extent, the problem with home country bias is mitigated and low-quality patents are significantly screened out.

In the remainder of this section, the level and the structure of inventive outputs in Europe, Japan, and the United States are compared by using OECD triad patent family database. The dataset of October 2008 version with 738,295 family counts is used. We use a partial count of number of families by location of applicants. Figure 7 shows the trend of family counts originated from each of the three countries and region by priority year. These datasets cover the patent family information with priority year from 1978 to 2006. However, it should be noted that this dataset suffers from a severe data truncation problem, because it will take some years until a patent is applied for the same invention (or granted) for all three countries and regions. In addition, an average time period between patent application and grant in the USPTO data has increased to 35 months.[21] Therefore, the family count in Figure 7 shows a downward trend since the late 1990s.

It is interesting to see that all applications from three countries and regions show a similar pattern. A small drop in the trends can be found in early 1990s. This may be related to decreases in patent application to the JPO after the burst of the bubble economy and severe recession since the early 1990s. In terms of the number of patent family counts, the US applicants are always the largest, followed by European and Japanese applicants. Recently, the size of Japanese applications surpassed European applications, but it is significantly below the level of the United States. Therefore, an overall inventive activity of Japan, judged by patent family data, is under the US level, and simple patent counts in Figures 1 and 2 show a biased picture due to differences in patent systems across countries.

We have taken a further look at triad patent family data. First, the composition of the type of applicants is compared across countries and regions (Table 3). In all three, more than 90% of applications are coming from the corporate sector. In Japan, almost all applications are from this sector.

[21] OECD proposes some methods to estimating current trend of truncated data, called now-casting. For detail please refer to OECD (2008).

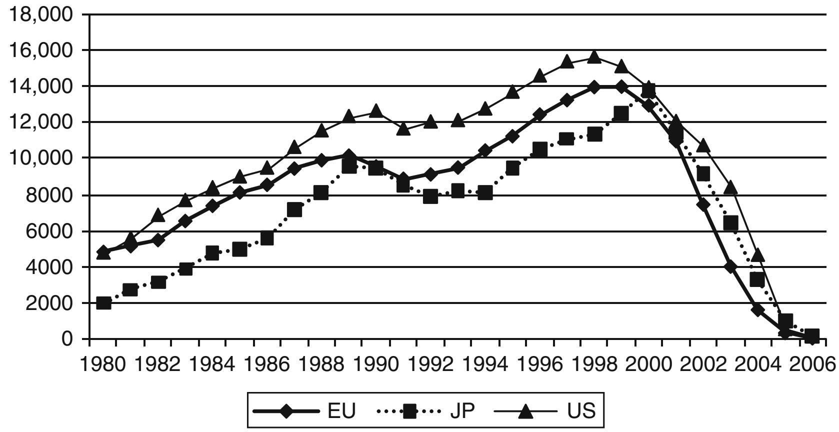

Figure 7. Number of patent families by origin.

In Europe, the share of individuals and nonprofit institutions, which are 7% and 2.2%, respectively, are a little larger than in the other two countries. In contrast, the share of university (2.4%) is relatively larger in the United States. This is consistent with the view of corresponding national innovation systems, in a sense that large corporations play a dominant role in Japan, while substantial contribution of individuals and universities can be found in the United States (Motohashi, 2005). However, it is important to note that the information on applicants or assignees does not necessarily indicate the organizations where inventions are made. In fact, Table 3 may underestimate the contribution of the inventors affiliated with Japanese and European universities, where the Bay-Dole like regulations and employee inventions rules for university professors have been only recently introduced. It has been found that the share of academic patenting in the United States and Europe is not so different, when individual patents applied by professors are taken into account (Lissoni et al., 2008). In addition, the survey on inventors in Japan and the United States suggests that the share of inventions by inventors affiliated with universities in triadic patents is very similar for the United States and Japan (just over 2% in the two countries, see Walsh and Nagaoka, 2009).

A variation of technology fields exists, where each country or region is active in patenting. Figure 8 shows the composition of technology class at the IPC section level for Europe, Japan, and the United States. As for European inventions, the shares of Section B ("Performing operations and transforming") and Section C ("Chemistry and metallurgy") are relatively large. In contrast, the shares of Section H ("Physics") and G ("Electricity") are larger in Japan. The technology composition in the US inventions is in between that of Europe and Japan.

Figure 9 shows a similar graph with the classification by industry of applicants. The conversion of technology class composition to industry classification is conducted by using the technology and industry concordance table, constructed by linking patent data with firm level line of business dataset in Japan (University of Tokyo, 2008). In all three countries and region, a substantial portion of the triadic patent families come from the electronics industry. This is particularly the case in Japan, and almost 40% of patent families are applied for by this sector. The second largest sector is chemicals

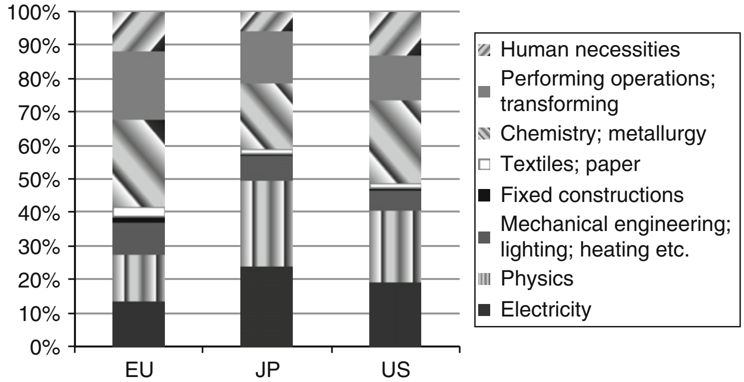

Figure 8. Technology composition by applicant origin.

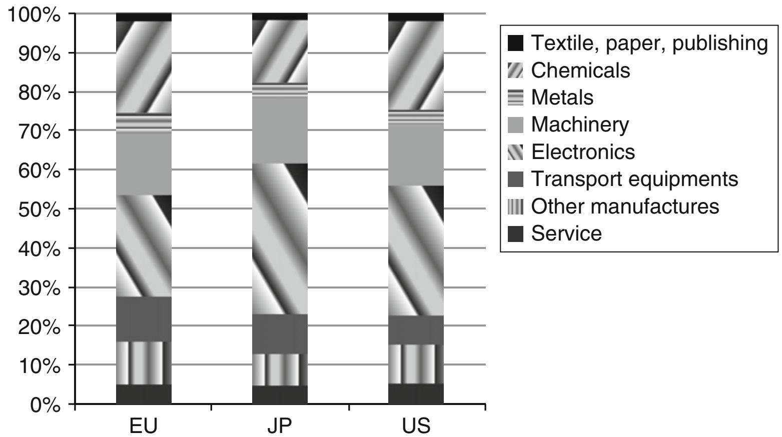

Figure 9. Industry composition by applicant origin.

(including pharmaceuticals), and the share of this sector is relatively larger in Europe and the United States. This picture may reflect relative technological competitiveness in these countries and regions.

4.2. Applications based on the patents applied earlier (continuation, continuation in part, and division)

Although there is often a presumption that a patent application or patent grant reflect the recent inventive activity, that is not necessary the case. Once an original application is filed, one or more applications based on the same invention can be filed later, enjoying the priority of the original application. Such practices are extensively used in the United States. According to Quillen and Webster (2006), continuing applications account for a third of the applications in the United States in recent years and, due to these practices, the effective grant rate of the United States can be significantly higher than the conventional statistics suggests (more than 90% relative to 60% for 2005). There are three types of continuing applications in the United States: continuation applications (CA), continuation in part (CIP), and divisions. The CAs and divisions provide the opportunities for a firm to obtain new patents with new claims, based on the patent application earlier made (the original disclosure), responding to the changing market situation unexpected at the time of the initial application.[22] These two practices are equivalent to "divisional applications" in Germany and Japan. Due to these application practices, there can be a large gap in timing between the invention and the patents.[23] In Japan and Germany, CAs are possible but under more stringent conditions. In the case of Japan, for example, such applications can be filed with no restriction only before the first action by the JPO to the patent examination request (rejection or grant by the JPO examiner), and significantly restricted after that. As a result, continuing applications ("divisional applications" in the Japanese) account for about 2.5% of all applications, significantly less than in the United States. In the context of a standard, these practices allow a firm to apply for new patents covering the standard even after the standard specification is set (see Bessen and Meurer, 2008; Nagaoka et al., 2009).

CIPs, which are unique to the United States, allow applicants to add new matters to the invention. In the other countries such new matter can be protected as a patent, only if it has enough inventive steps against the original patent application, since the original application serves as a prior art. This US rule allows an applicant to expand the scope of the patent *ex post* by strengthening the invention itself, unlike CAs and divisions if the original application is not published. These CIP applications are used significantly in the biotechnology area (see Hegde et al., 2007 for a comprehensive comparative empirical analysis of these practices).

These practices suggest several important points to be born in mind in using patent data for analyzing R&D and innovation performance. First, continuations applications are strongly endogenous to market opportunities and can be made long after the original inventions, so that such practices can significantly weaken the correlation between R&D and patent grants while they strengthen the correlation between sales and patent grants. Thus, it would make more sense to use priority year rather than grant or application year for sorting the patent data over years when using patent data for evaluating R&D performance, where such practices are important. Second, it would also make more sense to use the patent family which covers all CAs as a unit of analysis for analyzing the R&D performance, since all patents in the same family essentially are from the same invention and serve collectively to protect its appropriability, even though the application or grant years vary. For example, an analysis based on patents can result in an erroneous evaluation of the level of grant rate of patents for applications and the quality of R&D. The grant rate based on the patent counts may differ substantially across countries since allowable continuation practices differ across countries, but it may be more similar on the basis of patent family.

[22] A divisional application is made when the original application contains more than one invention although such application is supposed to be made as a response to the request by the patent office. In such case, one of the inventions is subject to continued examination and the other inventions can be pursued in new applications.

[23] An example may help clarify how these practices can cause a very long time delay between the invention and the patents. A US semiconductor firm made an application for a US patent in April 1990 (disclosed as a PCT application in 1991). It then applied 82 continuing applications based on that patent (62 continuation applications and 20 divisional applications) and got 79 patents by June 2004. It used four patents applied from 1997 to 1998 and granted in 1999 based on 1990 patent application for suing other firms.

5. Patent statistics and innovation activities

5.1. Framework

Innovation can be understood as a process of converting technological or nontechnological inventions, ideas, and knowledge into the new products, services, and processes to generate economic returns. Patents can be an input and an output of this process. In addition, patent statistics shed some light on innovation processes, such as knowledge spillover and collaborations in research. In this section, the role of patents in innovation activities is discussed. Patents have been treated as an output of the knowledge production function with R&D as an input, and an input to the production function to explain a firm's performance, such as productivity (Griliches, 1990). In addition, the number of patents can be used as a proxy of knowledge capital, used as one of the factor of inputs to the production function at firms (Pakes and Griliches, 1984). Figure 10 modifies the figure in Pakes and Griliches (1984). Patents can be generated by R&D and other inventive activities, and they are used for firm business activities captured by performance variables such as productivity and market value.[24]

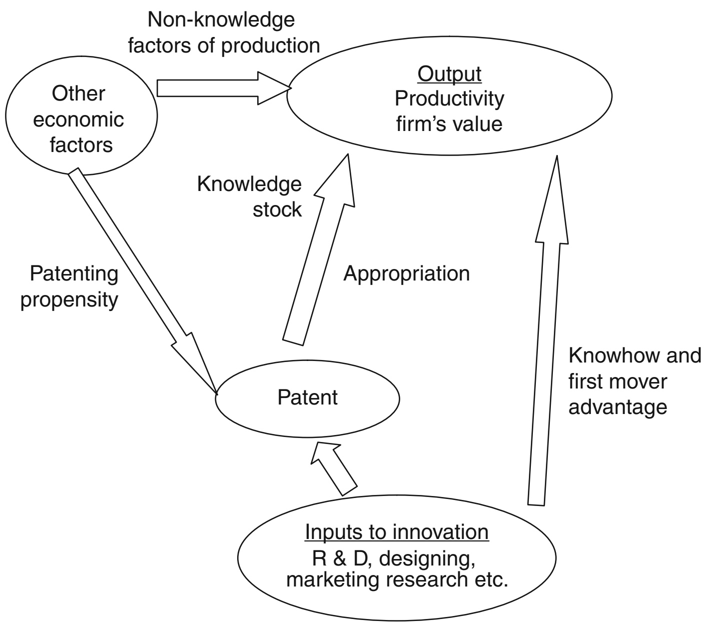

Figure 10. Framework of innovation indicators.

[24] Obviously, Figure 10 too much simplifies complicated nature of innovative activities. For example, development activities may differ considerably from research activities (Czarnitzki et al., 2009), although a substantial number of patentable inventions are generated from development (see Figure 13 and the related discussions).

Here, not all inventions are patented, so that there is a direct path from R&D to a firm's performance (know-how and first mover advantage path), since there are alternative tools for appropriating rents from inventions such as secrecy, complex design, and speedy product development (Cohen et al., 2002; Levin et al., 1987). It is also found that not all patents are used as an input to production function of firms. Only half of the patents owned by a firm are used either by them internally or licensed to others (Gambardella et al., 2007; Motohashi, 2008). The remaining half of the patents are taken out for strategic and other reasons. For example, a firm may keep her patent rights for blocking competitors' inventing around or preparing future negotiation for cross-licensing. Thus not all patents are considered to be "knowledge stock" and some of them serve only for appropriation, which still affects the output and value of the patenting firm. In addition, patenting is endogenous to market opportunities and to the size of the complementary assets of a firm, since the patenting propensity of a firm rises with the profitability of patenting. We will discuss limitations of patent data as an innovation indicator in this section.

It should be noted that the framework in Figure 10 may still capture the essential elements of the framework necessary for analyzing innovation, even though there are some limitations in patent statistics. In fact, Crepon et al. (1998) used French data to the system of three equations, (1) determinants of R&D, (2) patent production function (lower arrow in Figure 10), and (3) production function using patents as one of the inputs (upper arrow in Figure 10). As a data for knowledge capital, patents, and the share of new product sales from the French innovation survey are used separately. Both patents and the share of new product sales turn out to be effective indicator as knowledge capital. Recently, this econometric model was taken as a model for the OECD's innovation microdata project, and it was tried with similar datasets in 18 countries (OECD, 2009).

5.2. Patents as an innovation output?

When patent statistics are used as indicators for inventive activities, it should be noted that not all inventions are patented. The patent system ensures *ex ante* incentive for inventive activities by granting *ex post* monopoly rights to use the fruits of such activities. However, the contents of patent applications are disclosed in return. This benefits existing and potential competitors. In addition, enforcing patent rights can be costly. When you find any infringement to your patent, you have to take action (such as sending a warning letter, negotiation, starting legal processes, etc.) to recover any damage due to the infringement. Enforcing patent rights in a foreign country incurs additional costs. If these kinds of potential costs associated with patent applications and enforcement are greater than the benefits, you may not apply for a patent, but rather keep it as trade secret.

Other than patents and trade secrets, there are other mechanisms to appropriate returns from innovation. Speedy product development, complexity of product design, and control of complementary capabilities are also important mechanisms (Mansfield, 1986; Scherer, 1959). In the United States, the Yale survey on industrial research and development was conducted to understand such mechanism in 1983 (Levin et al., 1987). This was followed by the Carnegie Mellon Survey (CMS) in 1995 (Cohen et al., 2000). A comparative survey with the CMS survey was done in Japan by the National Institute of Science (NISTEP), and the results of two countries were compared (Cohen et al., 2002). In Europe, a similar questionnaire is included in the Community Innovation Survey (CIS), which is used for empirical studies on the effectiveness of patents for appropriation among others (Arundel, 2001).[25]

[25] Hall (2009) provides a concise overview of "innovation surveys" in Europe and the United States.

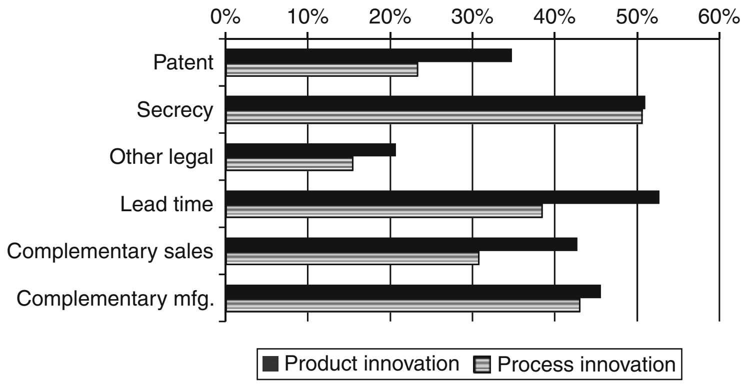

Figure 11. Importance of appropriability mechanism. Source: Cohen et al. (2000).

In the CMS, the following question is asked for product and process innovation separately, "What is the percentage of your innovation for which each appropriability mechanism was effective in protecting your firm's competitive advantage in the past three years?" (Cohen et al., 2000). Figure 11 highlights the results for the United States, providing mean percentages in each appropriability mechanism for product and process innovation. It shows that patent is not the most effective mechanism, but ranked only in the fifth position out of six for both types of innovation. As for product innovation, "lead time" followed by "secrecy" is perceived as the most effective mechanisms, while "secrecy" followed by "complementary manufacturing capability" is the most effective in process innovation. This explains the difference of patenting propensity for product and process innovations. According to Goto and Nagata (1997), 55.1% of product innovation was applied for patents, while for process innovation 29.7% was applied. The corresponding figures for the United States are 60.2% and 36.5%, respectively.

The CMS also inquired about the reasons not to patent for unpatented innovations. There are five potential reasons in the questionnaire, and "ease of inventing around" was found to be the most relevant reason. This was followed by "difficulty in demonstration of novelty" and "the amount of information disclosed in a patent application." This finding explains why patents are a relatively effective mechanism for appropriating rents from innovation in the pharmaceutical industry. New chemical entities in drugs can be protected by a compound patent, and there is no way to invent around it. On the other hand, for electronics equipment, hundreds of patents are involved with one product, and there are many substituting technologies for each patent. In these kinds of products, the effectiveness of a patent as compared to secrecy becomes limited. More generally, in discrete or simple technology products, the relative effectiveness of a patent is greater than in complex products, which comprises numerous separately patentable elements (Levin et al., 1987; Merges and Nelson, 1990). It is found that the patent propensity increases with firm size significantly, because larger firms can spread fixed costs of patent applications over a large number of patents (Arundel, 2001; Cohen et al., 2000). In addition, a small firm may have difficulty in enforcing its patent rights because of the significant legal costs.

It should be noted that the patent propensity differs by country. Cohen et al. (2002) compare the CMS data in the United States with the NISTEP data for Japan. The main finding is that Japanese firms perceive patents to be about as effective as any other appropriability mechanism. In contrast, the US firms perceive patents to be less effective than other mechanisms such as secrecy, lead time, and complementary capabilities. It is also found that Japanese firms perceive patents as an information source of rivals' R&D more strongly than the US firms. One of factors behind such differences might be the different characteristics of patent systems in the two countries (Cohen et al., 2002).[26] The patent system is built upon the balance between exclusive rights and information diffusion. According to Ordover (1991), the US system puts emphasis on the former, while the Japanese system is inclined toward the latter at least in the past. For example, the contents of patent applications were not published until 1999 in the United States while all patent applications are made public within 18 months of application under the Japanese system. In addition, the US system relies on the "first to invent" principle, while the Japanese system is based on the "first to file" principle. It should be noted that these characteristics of the US patent system are unique in the world, while that of the Japanese system is more or less similar with that of the European countries.

The JPO has been conducting a unique survey called the Survey of Intellectual Property Activities every year since 2001. This is a firm level survey and covers about 7500 patent (and other intellectual properties) applicants, which includes firms, universities, and research institutes. In a 2007 survey, the JPO asked a question on the number of inventions reported to IP departments of applicants as well as the number of patent applications. Figure 12 shows the ratio of patent applications filed to the number of reported inventions. This ratio varies by industry from over 90% in food, textile, pulp, drugs, and

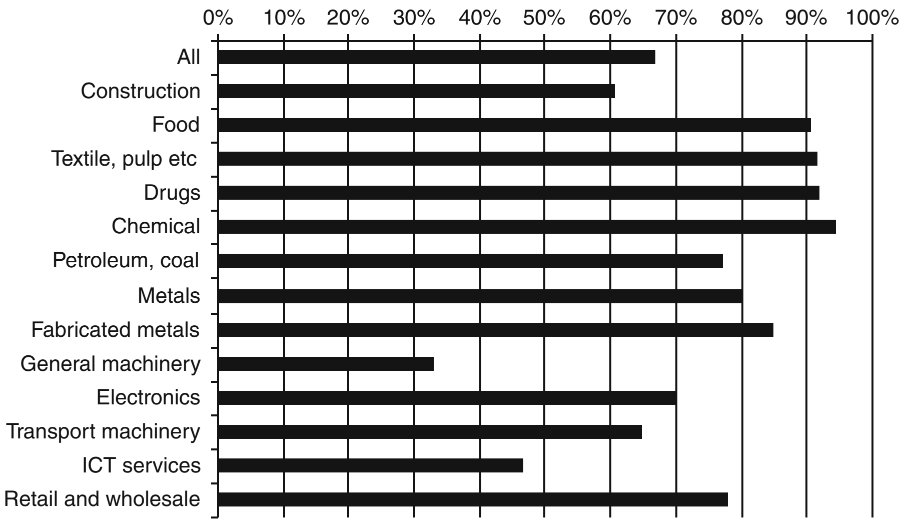

Figure 12. Share of patenting inventions. Source: Survey of Intellectual Property Activities (2008) (JPO).

[26] One reservation to this interpretation is that the Japanese inventors perceive foreign literature (both patent and science) more important than the Japanese domestic literature (see Walsh and Nagaoka, 2009). Then, an alternative explanation is the difference of absorptive capability of inventors of the United States and Japan, since PhD is significantly more prevalent for the US inventors than for the Japanese inventors.

chemicals to below 50% in general machinery and ICT services. This pattern is consistent with the different importance of patent protection in discrete industry and complex technology industry.

Another important fact that patent is significantly generated outside of R&D is suggested by the recent survey on the US and Japanese inventors. It suggests that more than 10% of the triadic patens do not involve R&D at all (see Nagaoka and Walsh, 2009). Since the survey focused on the patent with the earliest application date in each family with a common priority, it does not cover the continuation patents based on earlier applications. These patents are generated as a byproduct of non-R&D tasks such as manufacturing or design or even from the IPR department. Moreover, another 10% of the patents involve only the development stage of research. Non-R&D patents are more significant in small and medium sized enterprises.

Since patentability requires both novelty (and inventive step) and utility, we might expect that applied research is most likely to produce patents among three stages of R&D. Basic research might not be likely to lead to patents at least directly since a patentable invention must have a specific utility. And development might not easily generate patentable inventions, since it contributes less to knowledge production and the knowledge gained is more likely to be anticipated and therefore obvious. However, as shown in Figure 13, such is not the case. The inventions from pure

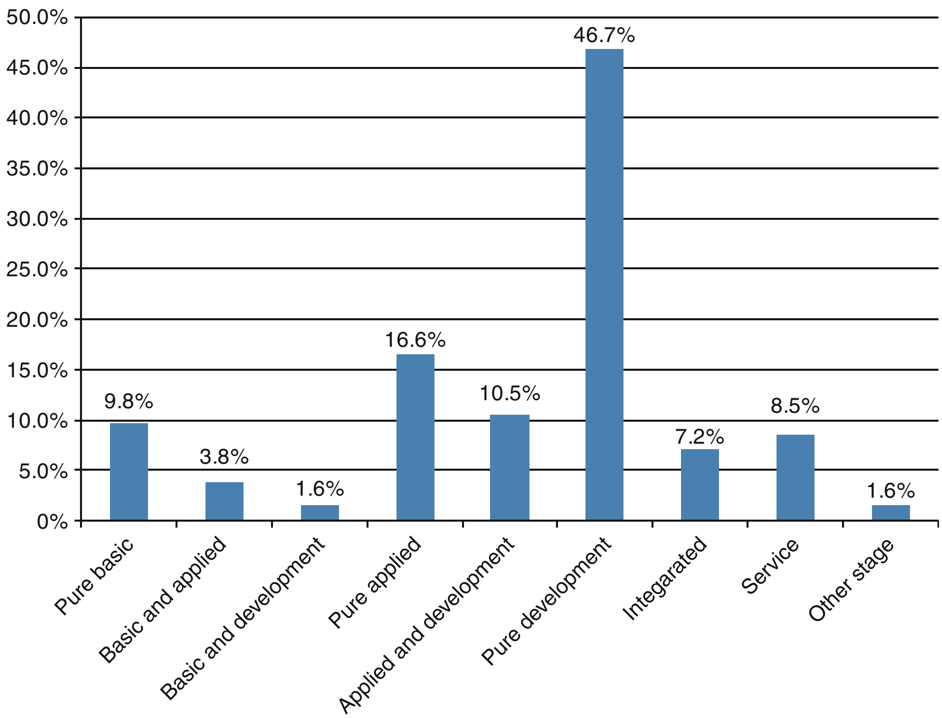

Figure 13. Where does an invention come from? *Note*: The proportion of the patents from each stage in the total sample of triadic patents. Source: Made from the RIETI inventor survey.

development account for almost half of the patents in Japan, and basic research also significantly produces patents. If we use the number of patents from pure basic research, pure applied research, and pure development for allocating the patents from the research with two or more of R&D stages, basic, applied, and development stages account for 13%, 24%, and 63% of the total patents, respectively (neglecting the patents from technical service or the other stages). On the other hand, these three stages of research accounts for 6%, 21%, and 73% of industrial R&D in Japan, respectively. Thus, while basic research is most productive in terms of number of patents per R&D dollar, patents are significantly produced in each stage of research and development, very roughly corresponding to the expenditures, which may explain the contemporaneous movement of patents and R&D as pointed out by Hall et al. (1986).

5.3. *Patent as a knowledge input of production function?*

Although patent statistics are useful for measuring a knowledge input to production function, it has some problems too. A firm's incentive for patenting is much more complex than just using a patent as knowledge capital input. Motohashi (2008) uses the data from the Survey of Intellectual Property Activities by the JPO to classify patents into several categories of use, as is shown in Figure 14. Every patent owned by a firm can be classified as (a) neither used in-house nor for licensing out, (b) used only in-house, (c) used both in-house and for licensing out, or (d) only for licensing out. A "blocking patent" in this survey is defined as an unused patent that a firm does not intend to out-license. Based on these datasets, Motohashi (2008) constructs five types of indicators reflecting a firm's patenting motivations, and some descriptive statistics for these indicators are presented in Table 5.

It is found that around half of patents are not used, either internally or by licensing to other firms. In drugs, this figure is as high as 63%. In this industry, R&D takes as long as 10–15 years for new drug to be introduced into the market. Therefore, there are a substantial number of patents, still in the process of R&D and not used for drug in the market. In the framework of Figure 10, the numbers in Table 5 mean only half of the patents are directly used for in-house production and sales activities. Of course there are other reasons that a firm holds unused patents. Some of them are held in the hope that they may be used in the future. More than half of unused patents are kept as blocking patents, in a sense of preventing other firms from using such technology. Others may be kept because a firm needs them for future licensing negotiation, particularly in the electronics industry where cross-licensing is relatively common (Hall and Ziedonis, 2001).

It should be noted that nonnegligible fractions of patents are licensed out, which may generate licensing revenue but does not contribute to a firm's own production. The share of licensing patent to total patent substantially varies by industry. It is particularly high in such industries as the other services industry. This industry includes a large number of R&D service firms such as biotechnology start-ups that have a strong incentive to license out due to a lack of complementary assets for internal use (Arora and Fosfuri, 2003). All of these findings suggest that we need a more complex model of patenting and R&D to take into account the various motivations for holding patents. A great cross-industry variance suggests the importance of industry specific modeling. In addition, the variance in indicators is also found to be large across firm size (Motohashi, 2008).

Patterns of use

	Variable		Variable
Not used	a	Blocking	a1
		Nonblocking	
Exclusive own use	b		
Own use and license out	c	Cross-licensing	cd1
		Noncross licensed	
Only licese out	d	Cross-licensing	cd2
		Noncross licensed	
			All

Definition of IP use indicators

	Definition
No-use	a/All
Block	a1/a
(Own) USE	(b + c)/All
License	(c + d)/ALL
CROSS	(cd1 + cd2)/(c + d)

Figure 14. IP use indicators and their definitions. Source: Figure 2 of Motohashi (2008).

Table 5
Descriptive statistics of IP use indicators

	No-use mean (%)	Block mean (%)	Use mean (%)	License mean (%)	Cross mean (%)
Food industry	51.7	64.5	43.6	4.9	0.4
Textile, pulp, paper, publishing	46.4	80.5	48.8	2.6	1.5
Chemica1s (excluding drugs)	52.9	76.2	42.6	3.5	2.3
Drugs	63.7	47.0	27.8	6.7	1.0
Metal and metal products	42.9	71.0	55.5	3.9	2.9
General machinery	40.5	76.0	56.0	3.5	4.0
Electronics and electrica1	46.8	67.2	47.2	7.5	9.0
Transportation machinery	58.0	64.4	38.9	3.3	5.1
Precision machinery	48.4	74.6	46.1	4.3	6.9
Other manufacturing	45.6	75.7	49.8	4.3	3.0
Construction	54.1	62.8	40.2	11.4	1.1
ICT services	56.6	44.8	32.4	9.7	0.0
Wholesale and retail	41.4	76.1	54.6	2.7	0.0
Financial services	26.4	33.3	70.5	3.9	0.0
R&D and related services	52.0	43.3	32.6	13.3	0.5
Other services	63.1	26.1	20.3	17.4	0.6

Note: See Figure 14 for definition of variables.

6. Valuation of a patent

It is well known that private value distribution of patents is highly skewed. There are some patents which provide substantial private value to the patent assignee. For example, the value of a patent for successful pharmaceutical products can be over one billion dollars. However, this kind of patent is only a very small fraction of millions of patents. Therefore, just counting numbers of patents of a firm or country without paying attention to their value can be misleading. The value of a patent consists of two parts, (1) the value of inventions *per se* and (2) the value of patent rights, in a sense of incremental value of patenting the inventions (Hall, 2009). However, it is difficult to separate these two parts empirically. Arora et al. (2008) is a rare example to estimate the latter value ("patent premium"). It is found that the value of patenting is estimated to be a 40% discount of the value of invention since demerits of patenting such as information disclosure outweighs the merits of invention protection. Therefore, a firm does not patent all inventions. However, if only patented inventions are included, the patent premium is estimated to be 47% on average. It is also found that the patent premium increases with firm size and is particularly large for medical instruments, biotechnology, and drugs.

For most of patents which are not traded in the licensing market, the actual value of patents cannot be directly observed. Therefore, we have to rely on indirect measures reflecting patent value. One of commonly used indicators is the number of forward citations, which is the number of times the patent in question is cited in other patents later. Other indicators include patent renewal, family size, and opposition and litigation information. In the following, first, pros and cons of such patent quality indicators are discussed. Then, the following subsection reviews empirical literature that investigated the relationship between patent quality indicators and the private value. The value of patent can be estimated by using econometric models based on firm value at stock market, or by questionnaire, often called an inventor survey. These and related literature are reviewed.

6.1. Patent quality indicators

6.1.1. Forward citations

The number of forward citations reflects the technological importance of the patent. Technological progress is cumulative so that inventors stand on the shoulders of others for further progress. In this sense, a large number of forward citations mean that the patent serves as a giant shoulder for many other subsequent innovations. It also means that such patent tends to yield more profit for the inventing firm, since the invention is technologically more important and it may have wider applications. Forward citations can also be used as an indicator of the social value of a patent, because an inventor of subsequent innovations might have saved the R&D costs by learning from the technological contents of the citied patent. In this sense, the cited patent has a social value, which is equivalent to the cost saving by reduction of R&D duplication in this case. The nonrival nature of knowledge makes it possible that the social welfare increases as the number of such citations increases. This social welfare gain may also lead to the private returns to the patent holder because he can engage in a number of licensing deals.

There are several points that should be noted when forward citation is used. First, patent citation takes time, so forward citation indicators suffer from a truncation problem, that is, only a small number of citations are realized for younger patents. One way to deal with this problem is to use the forward citations within the first 5 or so years, because more than 50% of citations received in the entire life of a patent occur within the first 5 years for the USPTO patents (OECD, 2008). In addition, the number of citations varies by the technological field of a patent. According to Figure 15, the average citation in biotechnology was 5.3 while that of computer software was 19.9 for the triadic patents of the US origins

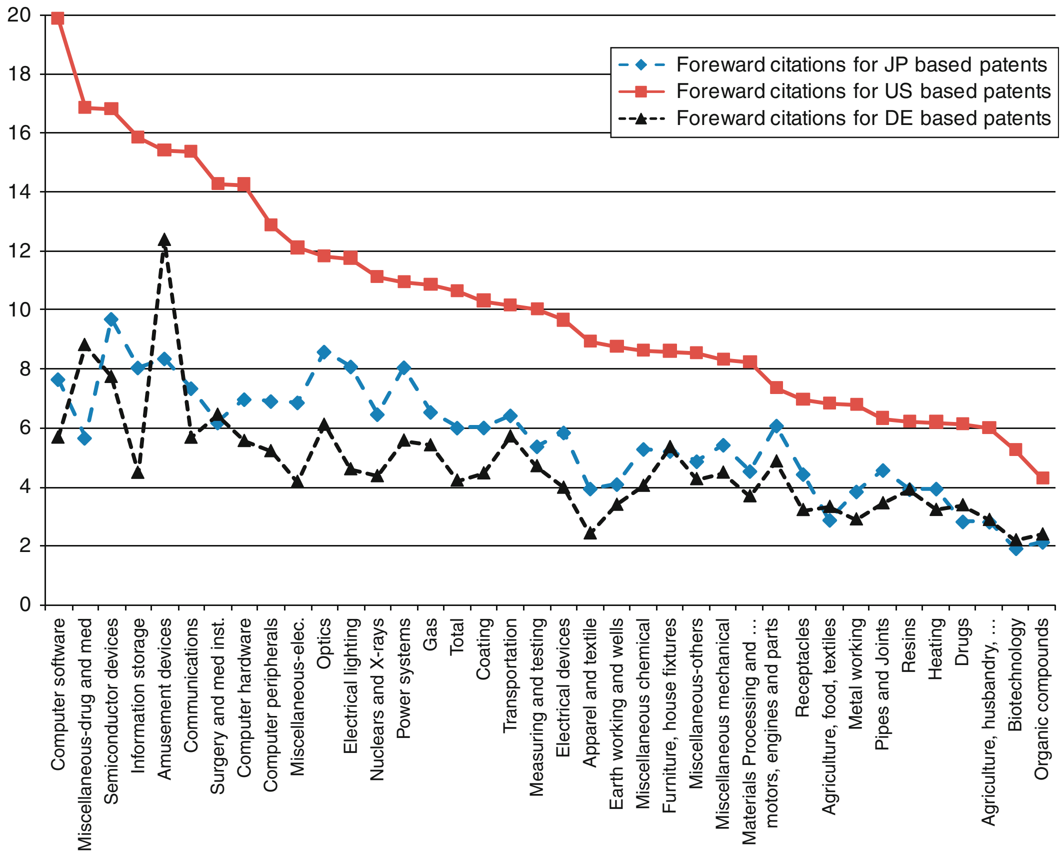

Figure 15. Foreward citation from the US patents for the OECD triadic patents by origins (priority years: 1995–1999). *Note*: The patents of the US origin include both the US inventors and the US applicants. The patents of JP and DE origins are similarly defined. Source: Prepared from PATSTAT and the OECD triadic patent database.

(with both US inventors and applicants) from 1995 to 1999. One way to control them is to use relative forward citation counts within the same application year and technology field. Third, the laws and practices regarding citations are different across countries. As pointed out in Section 2, under the US patent system, an applicant has to cite all relevant patent and nonpatent literature on the front page of the patent application, in addition to the citations made by examiners. In contrast, patent citation data at the EPO is generated in a process of patent examination. In the search report, the EPO examiner is supposed to provide a minimum number of the most relevant prior art references. The Japanese system is closer to the European one, in the sense that citation is provided by the patent examiner, instead of the applicant. Reflecting these differences, the number of citations per patent is substantially larger for the US patents than EPO or Japanese ones.

Home country bias can be found in patent citation data as well. More than 90% of references in the search report at the USPTO and the JPO for PCT applications cite documents of the home country (Michel and Bettels, 2001). Goto and Motohashi (2007) compare citation information of the EPO, JPO, and USPTO, by converting all citing and cited pairs in each national patent into OECD triad patent family-based information. About 750,000 citing and cited patent family pairs are identified in this exercise, and only 2609 pairs are identical for all three datasets by the EPO, JPO, and USPTO (Figure 15). This result suggests that the citation data in the three patent offices contain different information, even after home bias is controlled for by using patent family information.

6.1.2. *Patent renewal information*

Under the patent system, a patent holder has to pay periodic fees to maintain her patent rights. Therefore, one can assume that the longer a patent right is kept, the greater its economic value. In most countries, the patent renewal fee increases over time after the year of the patent grant. Only a small numbers of valuable patents are kept until the patent expiration date. In this sense, patent renewal information is useful to estimate patent value (Griliches, 1990).

Schankerman and Pakes (1986) employed patent renewal data from France, Germany, and the United States in the model of patent value, taking into account both current return to patent protection and option value associated with future use of patents.[27] As a patent gets older, the option value decreases as the intrinsic value of the patent gradually becomes known and the remaining patent term becomes shorter, although there are a small number of welcome surprises in the sense that some patents turn out to be valuable. However, most patents have little or no value, and as such, patent holders cease to renew them. Therefore, the distribution of patent value becomes more skewed toward the later stage of the patents life. One important implication from this study is the private value of a patent does change over time.

Schankerman and Pakes (1986) proposed the methodology and did estimate the patent value. For example, the median point of realized value of a patent is \$534 for France and \$6252 for Germany. The distribution of the patent value is quite skewed and about a quarter of French patents are worth only \$75 or less. At the same time, about 7% of German patents are worth \$50,000 or more. The relatively higher value for German patents over French patents is due to the stricter patent examination process in Germany. Only 34% of applications are granted in Germany, while the corresponding figure for France is 93%.

[27] See Pakes (1986) for a theoretical framework based on the view of the patent right as an option.

Thus, patent renewal information is a valuable source from which we could draw some quantitative information on the value of a patent during its lifespan. However, there are some drawbacks. One major drawback is its timeliness. We have to wait until the end of patent life to conduct an analysis according to the framework like Schankerman and Pakes (1986). It is very difficult to evaluate the value of young patents with this methodology. Another is that it has a truncation for the value of the most valuable patents all of which are maintained toward the end of the statutory limitation. A final related point is that the outcome depends strongly on the assumption on the value distribution or on the underlying stochastic process. These points should be kept in mind when working with patent renewal data.

6.1.3. Patent family size and other indicators

The number of countries for which the same invention is patented (patent family size) is also an important indicator of patent quality (see Harhoff et al., 2003a; Lanjouw et al., 1998). International patenting is much more costly than domestic applications. In addition, the fact that a patent holder wants to secure patent protection in various countries and regions, implies that she has a higher expectation of return from the patent. In contrast to patent renewal data, the patent family size is available in a more timely fashion. It is not necessary to wait for a patent to be granted, because the fact that a patent is applied internationally suggests the applicant's higher expectation for the patent. One point which should be noted is the timing of observation. Under the PCT rules, an applicant can keep the first application date as the priority date for 30 months. Patent grants come after this period and take several years depending on the country.

Opposition to patent grants and patent litigation information can be used as a patent quality indicator as well. Such actions are not free, and the opposing party must see some economic value greater than the legal cost (Harhoff et al., 2003a; Lanjouw, 1998). However, a major problem with this indicator is that only a small fraction of patents are opposed or litigated. In addition, again, timeliness is a problem. There are some other indicators for patent quality, such as the number of claims, number of technical classes, the number of inventors, etc. A more detailed discussion on these indicators can be found in OECD (2008).

6.2. Evaluation of patent quality indicators

The first sets of empirical studies are econometric studies by using matched datasets of patent data and financial accounting data of listed companies. These studies are based on the following model of firm level market value function (Griliches, 1981):

$$V_{it} = q_t(A_{it} + \gamma K_{it})^{\sigma}$$

V is the market value of firm i at time t, which is explained by A as physical assets and K as knowledge (intangible) assets. γ is the shadow price of K to A, σ is an elasticity of total asset to market value and q is included to absorb idiosyncratic macro level stock and market fluctuation. Taking a logarithm of the equation gives the following equation:

$$\log V_{it} = \log q_t + \sigma \log A_{it} + \sigma \log(1 + \gamma(K_{it}/A_{it}))$$

When we assume constant rate of return of this function ($\sigma = 1$), then the equation can be converted to the following Tobin's Q equation:

$$\log Q_{it} = \log(V_{it}/A_{it}) = \log q_t + \log(1 + \gamma(K_{it}/A_{it}))$$

As a variable for K (knowledge stock), R&D and patent stock are used (Griliches, 1990). Hall et al. (2005) use citation weighted patent counts as a variable for K to test the validity of forward citation as a patent quality indicator. They found that an extra citation per patent increases market value of a firm by 3%. It is also found that this relationship is not linear in the sense that the positive impact of citations per patent is particularly strong for firms with large numbers of citations per patent. This finding suggests that there is an increasing return of citation count to the patent value. An increasing return of citation is also identified in the study of social welfare index of computed tomography scanner innovations as well (Trajtenberg, 1990), which found a close relationship between citation-weighted patent counts and the social value (or spillover to consumers) of their product innovations. Another interesting focus of this study is to investigate the impact of self-citation to the patent value. Self-citation refers an inventor's citation of his or her own prior inventions, and Hall et al. (2005) show that the number of self-citations per patent gives a premium rate of return to a firm's market value on the total number of citations per patent. Self-citation can be interpreted as an accumulation of inventions in a particular technology in a firm which may lead to a stronger competitive position. In addition, the self-citation variable may inform us about the extent to which firms have internalized knowledge spillovers (Hall et al., 2005). Therefore, the number of self-citations can be used as a separate indicator for patent quality.

Citation count is just one of various patent quality indicators. There are pros and cons for all indicators, and we might be able to get a better one by combining these indicators. Lanjouw and Schankerman (2004) proposed a one-factor model and a composite indicator of the number of claims, forward and backward citations, the family size, and the number of the technology area (US patent classification system), by six types of technology. First, they have shown that all four indicators have some information about patent quality. In terms of the weight to the composite patent quality index, forward citation is the largest for drugs, while claims are loaded most heavily for the remaining five technologies, such as biotech, other health, chemicals, computers, electronics, and mechanical. They also point out that the 84% increase in patent citations from 1985 to 1993 can be explained by factors other than quality improvement, such as computerization which lowers the cost of citation. Finally, it is shown that mean quality at the firm level is positively related to Tobin's Q of the firm.

Another methodology of research on evaluating patent quality indicators is to use data obtained by questionnaire surveys such as the inventor survey. For example, Harhoff et al. (1999, 2003a,b) conducted a survey to investigate the value of patent citation. In a survey of German and the US inventors who registered their patents at the German Patent Office, one of the questions posed was, "what is the smallest amount for which you would have been willing to sell this patent?" The survey reported that the distribution of patent value is highly skewed. According to Scherer and Harhoff (2000), about 10% of the most valuable patents account for more than 80% of the value of all the patents, based on their survey of German patents. Harhoff et al. (1999) also ran the regression, showing a significant correlation between the citation count and the value of patents, which is consistent with the results of

Hall et al. (2005) at firm level. Similar surveys were conducted for European countries (Giuri et al., 2007), Japan, and the United States (Nagaoka and Walsh, 2009).

The advantage of this approach is that it enables us to understand the link of indicator and value at patent level, instead of firm level. In addition, this approach is based on a direct response from an inventor, as compared to indirect observation of the value in financial markets. However, on the other hand, a direct response means there might be subjective judgment. Also, a survey can cover only a small fraction of patents, typically only valuable patents, so that the results from this kind of study cannot be easily generalized. However, the results from these two types of studies are consistent with each other in general. This suggests various quality indicators in the previous section capture at least a fraction of the patent value.

7. Measuring knowledge spillovers from inventions

Measuring knowledge flow and spillovers across organizations and regions is a highly important and challenging issue. It is at the heart of the economics of knowledge, since its defining feature is nonrivalry in use, with important implications on appropriability, agglomeration, and increasing return at the economy level. Knowledge flow is also the central pillar for the endogenous growth theory initiated by Romer (1990). Such theory assumes that the knowledge created by R&D investment can be used freely by others for further advancement of knowledge. Griliches (1979) proposed to classify spillovers from R&D into two types, namely rent spillover and knowledge spillover. Rent spillover is generated when the quality improvement or output expansion of a firm, due to its innovation, affects consumers (a gain of consumer surplus), competitors (competitive loss of a competitor), or complementors (a gain of profit if its price exceeds marginal cost), being associated with no adequate payment or compensation. Rent spillover should not involve the productivity improvement of the recipient if measured properly, but it usually does since the price index usually underestimates the quality improvement due to the inventions. The other type of spillover is knowledge spillover, which helps to improve the efficiency of production or the R&D process of the receiving firms as they obtain useful knowledge—basically for free.

Patent information is highly relevant for assessing both types of spillover. As shown by the seminal paper by Scherer (1982), information on the possible use of a patent (in particular, whether it is for product or for process) would help us to identify the extent of the spillover of the R&D on downstream industry.[28] He showed that there has been significant "productivity" spillover from supplier R&D on users, perhaps mainly due to rent spillover but may not be limited to that. A further development of the study on rent spillover, using patent information is Trajtenberg (1990) mentioned in last section. In the rest of this section, however, we will discuss knowledge spillover.

There are two types of approaches that use patent information to measure knowledge flow. One is to use patent information to measure the technology distance between organizations, under the assumption that organizations, closely located in technology space, benefit more from the spillover from each other. Jaffe (1986) is a seminal work in this area. He constructed a measure of the technological distance,

[28] He distinguished product patents from process patents by assuming that the latter are those employed in their industry of origin.

based on the similarity of the patent portfolio of two firms, in terms of the US patent class. His method has been widely used since then. More recent empirical research focuses on citation as a measure of knowledge spillover, since it is supposed to be a more direct measure.[29] There has been substantial development of research using citation since the 1990s.

The seminal work of using backward citation or references of the patent to identify knowledge spillover was done by Jaffe et al. (1993). In this chapter, they found that more often than not, citations are made to patents from the same country, and further, it is more likely that they cite patents from the same state and from the same SMSA (Standard Metropolitan Statistical Area) of the United States. They interpreted this as evidence of localized knowledge spillovers. However, backward citation is still a controversial measure of knowledge flow. Griliches (1990) already pointed out the major issues almost two decades ago, which have not yet been completely solved. “Patent citations differ from usual scientific citations to the works of others in that they are largely the contribution of patent examiners. . . In that sense, the ‘objectivity’ of such citations is greater and may contribute to the validity of citation counts as indexes of relative importance. But in another sense, they are like citations added at the insistence of the editor. . . are not a valid indicator for channels of influence, for intellectual spillovers.” In the following, we will discuss these issues in detail.

7.1. Does backward citation represent knowledge spillover?

The primary reason for including references in patent documents or in a search report is to identify the prior art, which are relevant for evaluating the patentability of the invention in terms of novelty and inventive step. Thus, patent examiners, rather than patent applicants, are ultimately responsible for the citations made for this objective. This is very clear in the EPO where the citation information is provided by the search report. In Japan too, the citations disclosed in the patent grant documents are identified by the examiners as the relevant prior art for the granted patent.[30] In the United States, even though a significant amount of references are attached by the inventors due to the extensive disclosure requirements, examiners add the references if needed. According to Alcácer and Gittelman (2006), two-thirds of citations on the average patent are inserted by examiners and 40% of all citations (citing-cited pairs) were added by examiners for the period from January 2001 to August 2003, implying that examiners add citations more when the patent applicants or inventors fail to cite any reference or only a small number of references. Thus, when there is important prior patent or nonpatent literature on which the invention is based, it is very likely to be cited as prior literature. Even if the applicants prefer not to cite it, in order to reduce the risk of losing the patentability of his invention in light of inventive step, the examiner would need to identify it.

Thus, the question is how much backward citations represent the actual flow of knowledge. Jaffe et al. (2002) did a direct survey on inventors to validate backward citation in the United States as a measure of knowledge flow. They found that about 38% of respondents indicated that they had learned about the

[29] The identification of knowledge spillover based on the covariations between patent production and the neighboring firms’ R&D faces a serious endogeneity problem.

[30] The inventors used to add voluntarily the citations in the description part for the purpose of explaining the invention. The revision of Patent Law in 2002 has created a legal obligation for applicants to disclose prior relevant patents in patent application documents, which might have changed the nature of such citations by inventors in Japan.

cited invention either before or during the development of their own invention, while about one-third had learned about it after essentially completing their invention and a little less than one-third indicated that they had not learned about the cited invention before receiving their survey. Thus, the inventors were not aware of the majority of the cited patents, since they were given by the inventor's patent attorney or the patent office examiner. Duguet and MacGarvie (2005) provide evidence related to the legitimacy of citations in EPO patents as a measure of knowledge flows. Matching a sample of French firms' responses to the European CIS with a count of citations made and received by their EPO patents, they found that patent citations at the firm level are correlated to firms' statements about the technology flow to and from the firms. Finally, if backward citations represent the knowledge flow, we would expect that patents with more backward citations tend to have higher values, controlling the other determinants. Harhoff et al. (2003a) show that both the number of backward citations to patents and that to nonpatent literature has a significant correlation with the value of a patent, even if after controlling for the forward citations, family size, and the scope of the patents in terms of the number of IPC classes. This provides indirect support for backward citation as representing knowledge flow.

There may be differences between the backward citations to patent literature and those to scientific literature in their effectiveness as a measure of knowledge flow. Figure 16 shows the correlation between the number of backward citations to patent literature and to nonpatent literature (logarithmic scale) and the valuation by the inventors of the importance of patent and scientific literature as knowledge sources for the conception of inventions in Likert scale. It is based on the recent survey of Japanese inventors with respect to the triadic patents done in 2007 (see Nagaoka and Walsh, 2009). There is a significant positive correlation between the number of backward citations to nonpatent literature in a surveyed patent and the importance of science literature as a source of knowledge for the conception of an invention as evaluated by the inventor. The average number of backward citations to nonpatent literature is 1 for the invention for which science literature is not used or is not important at all, while it exceeds 4 when it is very important. On the other hand, there is no such correlation between the number of backward citations to patent literature and the importance of patent literature as a source

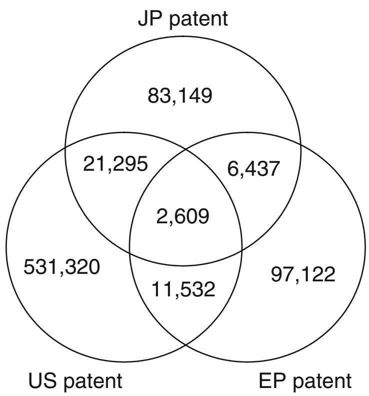

Figure 16. The number of citation pair matches across Europe, Japan, and the United States. Source: Figure A1 of Goto and Motohashi (2007).

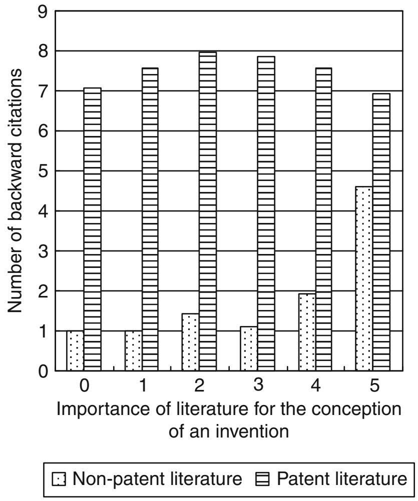

Figure 17. Importance of patent and scientific literature as knowledge sources for conceptions of inventions versus frequency of backward citations. Source: Made from the RIETI inventor survey.

of the conception of an invention. These results suggest that backward citations to science literature often predict better the knowledge flow than those to patent literature does (Figure 17). This may be because an earlier patent is cited not only because the technology described in that patent is important but also because of the other reasons such as the importance of its claim.

7.2. *Measuring knowledge spillover across organizations and geographies using patent information*

There are a number of studies using the citation as a measure of knowledge spillover. A seminal research evaluating the spillover from science to technology is Narin et al. (1997). They found that there has been rapidly growing citation linkage between US patents and scientific research papers and 73% of the papers cited by US industry patents are public science, authored at academic, governmental, and other public institutions. They also found that the cited US papers are from mainstream modern science; quite basic, in influential journals, authored at top-flight research universities and laboratories, relatively recent, and heavily supported by NIH, NSF, and other public agencies. As shown in Table 6 based on Chi Research Data, there is a significant variation of the frequency of citations of science literature by technology sectors. In biotechnology area, one patent cited 21 science papers on average during the period from 1998 to 2002. Such science linkage is also high for pharmaceuticals, agriculture, and chemicals. The study by Tamada et al. (2006) using the citations in the description of invention in the text of the Japanese patent documents confirms that there is a significant variation of science linkage among sectors and it is especially high in the biotechnology sector, reflecting the differing impact of science on technology. Science linkage varies significantly across firms, perhaps reflecting the difference in the absorptive capability of public science. Nagaoka (2007) shows that a firm with high science

Table 6
Average number of citations of science literature

1	Technology area	1998–2002
2	Biotechnology	21.0
3	Pharmaceuticals	14.6
4	Agriculture	8.1
5	Chemicals	5.5
6	Medical electronics	3.3
7	Medical equipment	2.4
8	Food and tobacco	1.8
9	Plastics, polymers, and rubber	1.3
10	Computers and peripherals	1.3
11	Other	1.3
12	Semiconductors and electronics	1.2
13	Aerospace and parts	1.1
4	Fabricated metals	1.1
S	Measurement and control equipment	1.0
6	Glass, clay, and cement	1.0
7	Industrial process equipment	0.9
8	Primary metals	0.9
9	Telecommunications	0.9
20	Oil and gas, mining	0.7
21	Miscellaneous manufacturing	0.6
22	Power generation and distribution	0.5
23	Wood and paper	0.5
24	Office equipment and cameras	0.4
25	Industrial machinery and tools	0.4
26	Textiles and apparel	0.4
27	Electrical appliances and component	0.4
28	Heating, ventilation, and refrigeration	0.3
29	Miscellaneous machinery	0.2
30	Other transport	0.1
31	Motor vehicles and parts	0.1

Source: Made from database of Chi Research Data.

linkage (more citation of scientific literature per its patent) tends to have a high-quality patent, controlling for technology by year fixed effects as well as firm fixed effects. It is important to note that high science linkage does not necessarily imply a direct one-way link from cited paper to citing patent, as pointed out by Meyer (2000). His case studies suggest that in some cases, technological developments as indicated by patents take place before their scientific rationalization given in research papers.

Citation information has also been used for assessing technology spillover across organizations such as those through alliances. One of the first attempts is Jaffe et al. (1998). Based on case studies, they found citations to be a valid, but noisy measure of technology spillovers and more specifically, excluding "spurious" cites, two-thirds of cites to patents of NASA were evaluated as involving spillovers. The most recent econometric study is that by Gomes-Casseres et al. (2006). Using patent citations as a proxy for knowledge flows, they found that citation probability was higher for alliances than for nonallied firms, and is higher for partners internal to the firm than those within alliances. They also found that the fixed effect estimation (a fixed effect given for each pair of firms) significantly reduced the coefficient of alliance, suggesting a significant endogeneity problem due to a missing variable, but the coefficient was still significant. Belenzon (2006) proposes to measure the internalization of spillovers by the ratio between the volume of indirect backward citations to their own patents and the volume of total forward citations to patents of the firm. He shows that higher technological internalization helps a firm to appropriate private rents and more general knowledge exhibits lower technological internalization, which provides some additional evidence for the usefulness of backward citation as a spillover measure.

The studies on localization of geographical spillover have received significant reassessment in recent years. The localization effects found by earlier studies seems to be driven significantly by the localization of industry, not by knowledge spillover. According to Thompson and Fox-Kean (2005), using finer technological classifications than those by Jaffe et al. (1993) and ensuring that the control and originating patents have at least one technological class in common, any statistical support for localization effects within the United States, found by earlier studies, is rejected.[31] Thompson (2006) proposes to use the examiner citations as the control, since examiners are not subject to geographic spillovers. Using this control, he finds that the distribution of inventor citations is more local than that of examiner citations so that localization effects exist, although the extent of localization identified is much smaller than that found by Jaffe et al. (1993).[32] Criscuolo and Verspagen (2008) found stronger localization of inventors' citations, using the same method with the EPO data. Patent citation information can be used to identify the channel of knowledge spillover. One important source could be the mobility of inventors. Kim et al. (2006) found that if at least one inventor on the patent had the experience of residing in a foreign country, the patent is significantly likely to cite the patents assigned to the assignees of that country, based on their newly constructed inventor-firm matched panel data.

[31] As for the finding of the localization at country level, it is important to note that the citation can be significantly biased in favor of domestic citations. That is, when there are two prior domestic and foreign patent literature protecting similar but not exactly the same inventions (one domestic patent by a domestic applicant and another foreign patent by a foreign applicant), the domestic patent is more likely to be cited for several reasons. First, the language difference would make the domestic patents to be more readily identifiable in prior art search. A patent office has more complete database of domestic patents (applications and grants) than of foreign patents, so that it depends more on the domestic patent documents search. Second, since there can be a difference in the rules for the description of the invention and the allowable patent claims across countries, the domestic patent is more likely to serve as the key patent literature for a patent office to evaluate the inventive step or nonobviousness of the patent.

[32] According to Jaffe et al. (1993), only 3.6% of the top corporate patents are localized for the control (1980) while the actual localization rate is 8.8%. On the other hand, the localization rate is 8.2% of the patents (2003 patents) according to the examiner citation, according to Thompson (2006).

8. Conclusion

There has been a significant expansion of the use of patent information for analyzing innovation in recent years. The important driving forces have been (1) the development of the large scale patent database not only in the United States but also in the EU, Japan, and other countries, and the availability of rapidly increasing computing power, (2) the implementation of surveys complementary to the official patent data, and (3) a better understanding of how the patent systems work. We have reviewed the major developments since Griliches (1990) in this chapter. We would like to give a brief summary and point out some outstanding issues in this regard.

The first notable development is the availability of patent data on an increasingly global scale and the accompanying global spread of research using patent data. Griliches (1990) focused significantly on the research based on the US patent data, with some exceptions on the research using patent renewal data, because of data constraints. The availability of global patent data has increased the value of patent information in a number of ways. Since there is a home county advantage in applying for patents, the patent data of one country, however comprehensive it is, may not be sufficient to evaluate the invention performance of that country, its firms or its inventors from an international perspective. From this perspective, the triadic patent database has been very useful for the purpose of international comparison of inventive performance of the United States, European, and Japanese applicants and inventors. The PATSTAT has opened up opportunities for anyone to create their own set of patent families on a global scale. Although the institutional difference of the patent systems across countries makes it necessary for us to be careful in extending the national analysis to an international scale (e.g., citation can have quite a different meaning across countries), the fact that patent systems differ from country to country would open up the possibility that we could tackle the issues for which the time series variation of national data cannot easily allow for, such as the effect of the patent system on innovation performance.

The significant expansion of research using citation information as well as better understanding of its nature has been another notable development, again due to the computerization of citation information. Citation information has been found to provide very useful information on the value of patents. Forward citation is found to contribute significantly to explain the market value and R&D relationship in the Griliches formulation, even if the endogeneity of a citation is controlled for. Backward citation as a measure of information flow is found to be more controversial. Although it was understood from the beginning that citations are often made by noninventors such as patent attorneys and examiners, its extent and consequences have been only recently investigated. We need to deepen our structural understanding between citation and knowledge flow. The survey information also suggests that the number of backward citations to nonpatent literature represents knowledge flow better than the number of backward citations to patent literature. Given that the knowledge spillover has important implications on appropriability, agglomeration, and increasing return at the economy level, developing methodology using backward citation information as a measure of knowledge flow, recognizing the incentives and constraints of those who cite, remains a very important issue.

The third major development is the extensive implementation of surveys such as the "innovation survey" of firms and the inventor survey. They have deepened our understanding of the usefulness and the constraints of bibliographic indicators based on patent data. These surveys have clarified that a patent is only one of several appropriability mechanisms, a significant proportion of patents are not from

R&D tasks, a significant share of inventions are not patented and a significant share of patented inventions are not used, and all of these shares are systematically related to firm and industry characteristics. Thus, we need to take into account these differences in the sources of inventions and in the patenting propensity, for instance, if one intends to evaluate R&D productivity of firms. While the skewness of patent value was understood early from the patent renewal study, the survey has an advantage of evaluating the upper part of the distribution. These findings suggest the clear importance of survey data to complement patent data in order to deepen our understanding of the innovation process.

The forth development is better understanding of the nature of the patent system and the reformulation of patent data for this objective. In this regard, a patent family data, based on priority information is important, given that a significant share of patents is applied for based on older inventions. It is very important to evaluate whether recent patent applications or grants are good indicators of inventive activities or simply for rent-enhancing activities on old inventions. It would make more sense to use the patent family, which covers all continuing applications, as a unit of analysis for analyzing R&D, since all patents in the same family are essentially from the same R&D (or related) project, even though the application or grant years vary. The analysis of the invention process based on patent families has just begun.

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