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The role of essential patents as knowledge input for future R&D

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ABSTRACT

Standards play a key innovation role in industries where a network effect prevails. A standard may contain important technological information that can serve as a basis of further innovation. This study empirically investigates how firms use essential patents as standard-driven technological knowledge for future R&D.

1. Introduction

Essential patents have been attracting much attention lately [1–8]. Firms have been striving to get their (usually patented) technological breakthroughs accepted as technical, and thus essential, standards—through the invention of advanced technology, for example [2]. Firms also eagerly participate in standardization. A study comparing the influence of technological advancement under a patent and the active participation of the patent owner [5] found the latter to be more influential in making a company's patent become essential as a standard. Creating alliances with companies operating outside a standard [9] and participating in the standardization process [7] are also effective ways to gain essential patents. A recent surprising study [8] shows that some firms participating in standardization use an opportunistic patent filing pattern: they file first and then bargain on behalf of their technologies at standardization meetings.

In principle, standardization is the process of setting a standard in order to stimulate innovation by establishing common technological bases of competition [10]. Thus, merely obtaining essential patents is not the primary motivation for participating in standardization. Standards are particularly important for innovation in industries where a network effect prevails [11]. Downstream markets can be formed based on standards, which can also drive R&D in those markets; advancements in downstream markets in turn provide R&D opportunities for the advancement of the standard [12]. This interdependent advancement dynamic produces continuous innovation. Although studies on patents and standardization have provided important implications, they focus on the essential patents' role as an important business asset and assume that producing this asset is what motivates participation in standardization. The question remains whether firms participate in standardization only to obtain essential patents or to achieve innovation in addition to setting a standard as well.

To address this question, we focus on essential patents' role as a knowledge source for future R&D. This study empirically analyzes how firms participating in standardization use essential patents as knowledge within standards to foster R&D. A finding that firms participating in standardization conduct R&D based on essential patents would suggest that they do not intend merely to obtain the patents, but strive for innovation over and above the standards to achieve the ultimate goal of standardization. Otherwise, we can conclude that their standardization efforts are designed to obtain only the essential patents rather than to achieve the goal of standardization.

The contributions of this paper are twofold. The paper provides an empirical investigation of standards as knowledge sources for R&D. Among the many studies on knowledge management (e.g., on internal vs. external knowledge [13–20]), none has shed light on standards as knowledge sources, despite their increasingly frequent adoption. A standard provides important technological information that can serve as a basis for further innovation. This study considers essential patents as a vehicle of technological knowledge within standards and tests how they behave as knowledge sources for R&D. Second, this paper provides evidence of firms' unbalanced R&D efforts during ongoing standardization as well as ex post standardization. Though firms' R&D efforts during standardization have been extensively studied, most studies on ex post standardization focus on legal issues such as fair, reasonable, and non-discriminatory (F/RAND) licensing rather

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than on R&D efforts. This study demonstrates that firms' R&D efforts during standardization are aimed at obtaining essential patents rather than establishing common technology bases for further innovation.

The rest of this paper is organized as follows. The next section discusses the knowledge sources for R&D. Section 3 formulates the study's hypotheses. Section 4 describes the data set used in this analysis. Section 5 presents our findings and tests the hypotheses formulated in Section 3. Section 6 concludes and outlines the study's policy implications.

2. Knowledge in essential patents

This chapter discusses how essential patents are different from other patents in their use as knowledge sources.

The use of knowledge sources for R&D has long been discussed among scholars, a typical example being internal and external knowledge. Naturally, internal knowledge sources contribute to firm innovation [13,15,19]. However, environmental changes such as shortened product life cycles, increasing technological complexities, and the increasing share of R&D expenses in total turnover have made it dangerous to rely only on internal knowledge sources. Firms must also use external knowledge sources to cope with environmental changes [16], while not relying on them completely. Maintaining balance in the use of internal and external knowledge sources is important [14,20].

Patent data are considered among the most precious knowledge sources for R&D. Technology is a most important factor in economic development. Patent data provide information useful in understanding new technology [21]. A patent document provides data such as the name of the breakthrough, its inventors and their addresses, and the applicants and their addresses. The most important piece of information, however, is knowledge of the invention. A patent system is intended to grant exclusive rights to inventions as much as to disclose knowledge about them. Thus, both essential patents and other kinds of patents provide technological information.

However, essential patents are very different from the others as knowledge sources. First, essential patents provide information about a technical standard. A patent becomes essential to a standard when the technologies used to implement it are legally protected by patents. Although a set of essential patents does not always equal a standard as such, essential patents always reflect the technological components of a standard. The main benefit of a technical standard, especially in a high-tech market, is the simplification it achieves by reducing uncertainties about the innovation [22]. Knowing a standard helps firms avoid wasting resources that would otherwise have been spent through uncertainties and thus increase their R&D efficiency. Second, essential patents are of a higher quality than are the others: they have more forward citation counts [2] and a higher technological value (when the forward citation count is used as a proxy for technological value [23]). Essential patents' endogeneity may be an issue [24], as being essential increases a patent's public visibility as much as it boosts forward citations. However, R&D does not terminate with the development of a standard. Participating firms must develop their R&D in order to improve the standard's efficiency, improve its operation, and create its next generation. Thus, despite their endogeneity issue, essential patents can be a valuable knowledge source for firms.

3. Hypotheses

In this chapter, we formulate our hypothesis. This study conducts in-depth analyses based on Wideband-Code Division Multiple Access (W-CDMA) and Long Term Evolution (LTE), considered the most successful 3G and 4G mobile communications standards. Both are standardized by the Third Generation Partnership Project (3GPP) Radio Access Network 1 group (RAN1). We found all the companies owning essential W-CDMA and LTE patents and participating in 3GPP RAN1 standardization and categorized them into four business models: non-practicing entities (NPEs), chipset vendors, manufacturers, and service providers. Our business model classification is consistent with one formulated by the Open Essential IPR Disclosure Database (OEIDD) [25], an essential patent database containing more than 40,000 intellectual property right (IPR) disclosures and commitment statements made public by IPR owners at main standardization bodies. In addition to essential patents, this database also provides companies' business models outlining their primary activity or dominant revenue sources. We confirmed that our firm classification is justified by the OEIDD's. We thus formulate hypotheses for each business model based on its R&D rooted in a technical standard.

The central hypothesis of this paper is that the selection of knowledge sources for R&D differs among business models. Each firm under study accrues different knowledge and expertise from different R&D and business experiences. Since innovation patterns are technology-specific [20,26], each firm has a different innovation pattern. However, some firms compete in the same business market. It is natural to assume that firms competing in the same market will face identical technological issues and hence will accrue similar technological portfolios.

3.1. NPEs

Non-practicing entities include universities and research institutes; this paper also considers an NPE any entity that does not practice its patented inventions and whose main revenue source is the licensing royalty and/or sale of their own patents [27]. Some may argue that NPEs' role in mobile communication innovation is ambiguous because they do not intend to implement their inventions. However, each component function used in mobile communications products is defined by technologies, many of which are probably protected by intellectual property rights. In this sense, NPEs' role in the division of labor is to create technologies with at least the potential for commercialization though they lack (tangible) products; therefore, NPEs must be included in this study.

In this business model, NPEs must have patents that generate direct licensing income and are easy to sell. For example, manufacturers must not infringe upon patents. It is thus in their interests to obtain essential patents, as they can then demand the licensing royalties generated from the use of the related technical standards. Reference [7] found that manufacturers' subsequent innovations after standardization are based on their own technologies, regardless of whether they are essential patents. By contrast, NPEs' innovations are based on essential patents, regardless of whether they are their own. Creating core competence [28] is not in an NPE's interest because having core competencies in specific technology fields does not necessarily equate to economically important patents in those fields. As NPEs are less confined to specific technologies than manufacturers are, their interest is to have soon-to-be essential or might-be-infringed-upon patents, from which they can earn licensing revenue. Accordingly, we derive the first hypothesis:

H1:. *Essential patents are an important knowledge source for an NPE's R&D.*

3.2. Chipset vendors

A chipset is a group of integrated circuits designed to work together; they are usually marketed as a single product. In a mobile communications system, a chipset, or part of a chipset, manages signal transmission and reception for communication, and its operation is defined by a mobile communications standard. Although the standard defines the operation, the implementation of the standard needs further R&D, during which one must consider factors such as operation reliability, cost performance, and implementation efficiency. It is therefore important for chipset vendors to conduct R&D based on the mobile communications standard. They need to accumulate unique own knowhow and skills that cannot be easily imitated by competing chipset vendors. Hence, a chipset vendor's own patents will likely be an important knowledge source.

Furthermore, a chipset functions as a "brain" for end products such as mobile terminals and systems. Manufacturers of mobile terminals, base stations, and systems are the chipset vendors' customers. Chipset vendors must know what their customers want in order to attract them. Hence, knowledge accumulated by others is also important for a chipset vendor's R&D, prompting the following hypothesis:

H2:. *Essential patents are an important knowledge source for a chipset vendor's R&D.*

3.3. Manufacturers

Chipset vendors and manufacturers can be classified into the same group when defined by the way they practice their inventions: both develop and market their products and are thus the opposite of NPEs. However, chipset vendors and manufacturers differ in terms of their positions in the supply chain. Manufacturers (such as the mobile terminal and base station manufacturers discussed in this study) buy chipsets and other components to produce their products. Although manufacturers participate in standardization and obtain essential patents, most of their revenue comes from downstream markets, which are not necessarily related to the technical standards. For example, they can manage revenues by optimizing supply chains or by providing various services. In addition, as mentioned, subsequent manufacturer innovations after standardization are based on their own technologies, regardless of whether they are essential patents [7]. Thus, although essential patents may be a knowledge source for manufacturers' future R&D, they are a less critical knowledge source for manufacturers than they are for NPEs and chipset vendors, leading to the hypothesis below:

H3:. *Essential patents as a knowledge source are important for manufacturers as well but not as important as for NPEs and chipset vendors.*

3.4. Service providers

Service providers buy products from manufacturers and provide communications services. Although product cost and performance are important to them, they need not develop the technology themselves. Hence, essential patents are not important for their future R&D. Even if they were more important, service providers would have the smallest incentive to do R&D based on patents among all the business models. Accordingly, the following hypothesis is proposed for chipset vendors:

Table 1
Summary of Hypotheses: The significance of patents in each business model's R&D.

	Reliance on essential patents as an R&D knowledge source
NPE	High
Chipset vendors	High
Manufacturers	Medium
Service providers	Low

Table 2
Database and retrieved information.

Database	Retrieved information
PATSTAT (Oct. 2011)	Application date, IPC, inventors, applicants, etc.
3GPP RAN1 Meeting minutes #1(21/1/99)–#60 (22/02/10)	Meeting participants list
ETSI Special Report 000314 Ver. Mar. 2012	Essential patents list in W-CDMA and LTE
Derwent Innovation Index	No. of patents assigned

H4:. *Essential patents as a knowledge source are not important for service providers and are the least important among NPEs, chipset vendors, and manufacturers.*

3.5. Hypothesis summary

We summarize our hypotheses in Table 1 below. The baseline throughout this discussion of essential patents as a knowledge source for various business models is service providers.

4. Data and analysis model

4.1. Data

This study uses PATSTAT (Ver. Oct 2011), 3GPP RAN1 meeting minutes, the European Telecommunications Standards Institute (ETSI) Special Report 000314 (Ver. March 2012), and the Derwent Innovations Index. Table 2 describes each database and the information used.

We use ETSI Special Report 000314 to identify the essential patents used in W-CDMA and LTE. Using ETSI Special Report has both advantages and disadvantages. One advantage is the large number of essential patents reported in the ETSI: a list of essential patents for W-CDMA and LTE is available from any of the standardization bodies collaborating under 3GPP, such as China's China Communications Standards Association (CCSA), Europe's ETSI, Japan's Association of Radio Industries and Business (ARIB) and Telecommunication Technology Committee (TTC), Korea's Telecommunications Technology Associations (TTA), and the US' Alliance for Telecommunications Industry Solutions (ATIS). As most essential patent owners declare under ETSI [3], most essential patents are declared to ETSI. However, essential patents are disclosed merely through their owners' declaration; no entity evaluates the declared essential patents' authenticity. Self-assessing the patents would require much time and expense. Using the ETSI Special Report, though not the best option, is the most efficient.

We use 3GPP RAN1 Meeting minutes to identify the inventors who participated in the 3GPP RAN1 standardization meetings. Though the meeting minutes provide the participants' names and affiliations, it is difficult to distinguish between the names of participants and inventors in the patent database. A matching process is employed. First, patent data are retrieved by roughly[1] matching the meeting participants' names with the inventors' names. Second, the meeting participants' affiliations are matched with the inventors' assignees in the patent database. Third, each entry is manually checked to confirm whether the data are correct, and patents found to be incorrect are excluded. This manual matching is used to extract the inventors' IDs from the patent database. Finally, the patent data are extracted using the inventors' IDs to handle

[1] In the minutes, inventors wrote their name in different formats: e.g., [First name] [Second name] [Family name], [First name] [Abbreviation of Second name] [Family name], [Abbreviation of First name] [Family name], [Family name] [First name]. I used all the possible pairs to find the inventors in the patent database.

cases in which patents invented by attendees have missing assignee information. Some inventors' names appeared to have been duplicated in the company names, especially large companies. We use international patent classifications (IPCs) for this study. We remove IPCs with essential patents and filter out the patents that do not belong to the essential patents' IPCs.

We construct the data set in the following way. First, we select the patent applications according to the owners of the essential patents for W-CDMA and LTE. Second, we find the patent applications classified in the IPCs of the essential patents for W-CDMA and LTE; many big firms, such as Nokia, Panasonic, and Samsung Electronics, have several R&D fields, some of which are not related to mobile communications, and finding the essential patents' IPCs allows us to identify those firms' mobile communications R&D. To find the list of essential patents in PATSTAT, we match the application numbers with the essential patent publication numbers provided in the ETSI Special Report. Third, we remove the essential patents and patent applications "aimed" at essential patents; these patent applications are isolated by extracting a list of patent applications made by the participants of standardization meetings (who are identified using the 3GPP RAN1 meeting minutes). We consider that they applied for the patents to develop a standard rather than to further a business. We are interested not in how essential patents play a role as a knowledge source for the next generation of a standard, but in how essential patents play a role as a knowledge source for a firm's R&D. Accordingly, excluding essential patents and patent applications aimed at essential patents helps us construct a patent data set for mobile communications technology by eliminating patents aimed only at setting mobile communications standards.

However, our data set construction follows several conditions. First, we use the patent data filed by firms that own essential patents. Second, we use the patent data filed with the U.S. Patent and Trademark Office (U.S. PTO). A patent can be applied for to more than one patent office. Firms owning essential patents and operating in global markets usually apply to the U.S. PTO because of the U.S. market's global significance and because patent applicants to the U.S. PTO must disclose the prior art behind an invention (in the "duty of candor"); consequently, patent applications to the U.S. PTO have many patent citations. Third, we use patent data filed after 1999, since the 3GPP RAN 1 standardization started in 1999. The 3GPP is a standard-setting organization established in the late 1990s to define a globally applicable system for mobile communication (GSM). The RAN1 is responsible for the specification of the physical layer of the radio interface and has defined the W-CDMA and LTE since their inception.

We obtained 28,801 patent applications made by 43 firms. Table 3 presents the data's statistics. The first column presents the business models considered in this research. The second, third, and fourth columns present the number of patent applications, the number of firms in each business model, and the number of patent applications per firm, respectively. The fourth column is obtained by dividing the second column by the third. Manufacturers are the largest entity in our data set (with 31 firms). Among the four business models, we note that chipset vendors and manufactures perform many R&D activities, perhaps because they generate products while the others (i.e., NPEs and service providers) do not. Most patent applications per firm are made by chipset vendors (at 1065.3 patents per firm), exceeding those of manufacturers (at 768.1 patents per firm) by 50%. Thus, chipset vendors conduct a great deal of R&D in this field.

Table 3
Data statistics.

Business model	No. of patent applications	No. of firms	No. of patents applications per firm
NPE	436	5	87.2
Chipset vendor	4261	4	1065.3
Manufacturer	23,810	31	768.1
Service provider	294	3	98.0
All	28,801	43	669.8

Figure 1 depicts the number of annual patent applications to the U.S. PTO. This number is fairly constant until 2005, after which it declines, perhaps because patent applications are published 18 months from the earliest filing date and are confidential until their publication; although a patent application can be published at the request of the applicant, this is rare. Thus, some unpublished applications might not have been counted. Additional uncounted patent applications might have been made under the Patent Cooperation Treaty (PCT). As mentioned, we consider only patent applications to the U.S. PTO; the non-U.S. firms included in our data would have considered their home countries' patent offices as their primary patent filing option. The PCT allows a patent application made to one patent office to be made to other patent offices within 30 months.

4.2. Analysis model

Our analysis uses a logit regression model, the observations for which are patent applications. The dependent variable is a dummy variable indicating whether a patent application cites essential patents (=1) or not (=0). Our use of a dummy variable rather than the number of essential patents in patent citations deserves careful discussion. It is widely understood that the more patents are cited, the higher the knowledge flow [21]. Accordingly, defining a dummy variable for patent citations rather than counting them might risk information loss. Nevertheless, we choose not to count them for several reasons. First, counting the essential patents in patent citations may not capture the degree of knowledge flowing from standards. A technical standard comprises a set of technologies within which no technology stands alone; they all work together as a single system. Inventors and applicants add several essential patents in their patent citations because the technologies they describe work together as a single function. Thus, having more essential patents in a patent citation does not necessarily imply that the invention is more strongly affected by the standard. Second, the knowledge flow from specific technological components is beyond our scope. Counting the essential patents in citations may provide information about how many technological components functioned as a knowledge source, but, again, this would not imply that the invention is most strongly affected by the standard.

An additional logit regression model is used to compare other R&D knowledge sources from essential patents; the knowledge

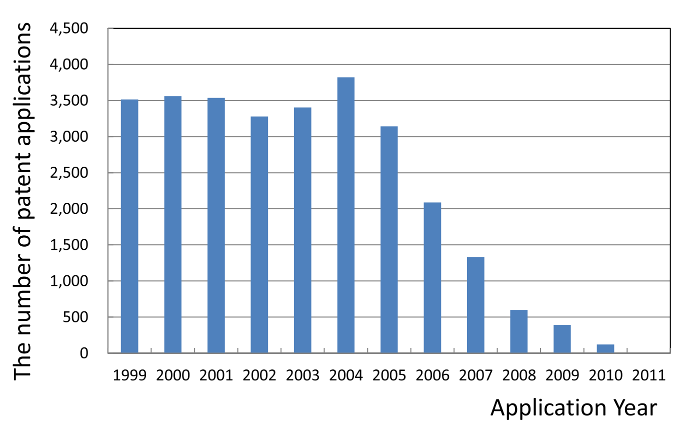

Fig. 1. Number of annual patent applications (there are 28,801 overall).

source in question is internal knowledge. The dependent variable is a dummy variable indicating whether a patent application cites any patents filed by the same applicants (=1) or not (=0). In this regression model, we do not consider the internal knowledge declared essential; we instead set the dependent variable to 0 if an internal patent application is declared essential. Patent applications, especially those to the U.S. PTO, must provide prior references. Thus, citation records in patent documents describe the knowledge that serves at the bases of the invention. Many studies have used patent citations as a proxy for knowledge flow [29,30], and we proceed according to that assumption.

The independent and control variables are the same for all three regression models. The independent variables are dummy variables for each business model. To avoid the dummy variable trap [31], we do not define the dummy variable for service providers. We use three independent variables: NPE, Chipset vendor, and Manufacturer. The value of an applicant's business model is set to 1. Thus, the baseline is Service Provider.

We also define dummy variables for each firm's home base. The firms used in our analysis are based in five regions: Europe, China, Japan, Korea, and the U.S. We define four regional dummy variables according to the applicant's home base by setting Europe as the baseline; China, Japan, Korea, and the U.S as well as the value of the applicant's home base are all set to 1. Among the five regions, Chinese and Korean firms are considered "following" manufacturers; thus, Asustek, HTC, Huawei, LG, Samsung Electronics, and ZTE are classified as followers in this study. Since they are all manufacturing firms, correlations between the independent variables are inevitable (see Appendix A for the correlation matrix). Our classification of followers might pose a concern; for example, Samsung Electronics is included as a follower. However, first, Fig. 1 shows that most data are for patent applications before 2006. Thus, although some of the six Chinese and Korean firms are market leaders now (in 2013), they were not in the mid-2000s. Second, even if the Chinese and Korean firms increase their essential patents (which may be evidence of competitiveness), their knowledge is still heavily dependent on the Triad [32]. Third, the other firms are from Europe, Japan, and the U.S. Since the Triad had local mobile communication standards in the initial stage of their mobile communication industries, their domestic firms accrued the technological capability to develop relevant systems. In the 1990s, for example, the second-generation (2G) communication standards were designed in different countries—the GSM in Europe, interim standard-95 (IS-95), better known by its brand name "cdmaOne," in North America, and personal digital cellular (PDC) in Japan. The GSM was standardized through the cooperation between competing companies under the European Commission's policy of widening European markets. The standardization of IS-95 was led by Qualcomm and that of PDC by Nippon Telegraph and Telephone (NTT). Consequently, we may naturally assume that the firms in those countries have attained a certain level of technological capability, knowhow, and skill.

We include several control variables in the regression mode to control for some critical influences. The first control variable is firm size. Big companies have more resources than small ones and can conduct large-scale R&D and manage their corporate strategies on their own. Large companies are also likely to have thick patent portfolios. We use the number of assigned patent applications as a proxy for firm size. This number is drawn from the Derwent Innovation Index and is computed through a logarithm; the logarithm value is used in the regression.

The second control variable is core technological competence. A firm with a core technology in a given field may have a large patent portfolio in that field, allowing it to improve its current technologies and develop complementary and future technologies; this might create a bias. To control for this, we use relative technology advantage (RTA) as a proxy for core technological competence [33,34]. The RTA is calculated by taking the ratio of a patent's share in related technological fields after determining the technological distribution of all the patents for which a firm has applied. A patent with a high RTA is understood as highly important to the firm.

The third control variable is absorptive capacity [35], which is important in R&D, especially in that using external knowledge. Firms with low absorptive capacity will fail not only to recognize new information but also to apply it to commercialization. Many methods of measuring absorptive capacity have been proposed [40]. We considered using R&D intensity [35] to reflect absorptive capacity, but finding some of the firms' R&D-intensity in their reports was impossible, as some firms no longer exist, and others do not make their reports public. Instead of considering the number of inventors and R&D-intensity as the absorptive capacity, therefore, we use the number of essential patents. The number of patents has been used to reflect absorptive capacity in previous studies [38,41]. Merely counting patents is limited as a way to measure absorptive capacity: our sample firms have many business units, which may have differing absorptive capacities. Thus, we count each firm's number of essential patents and use the result to proxy for the firm's capacity to absorb standard-relevant knowledge. We count the essential patents using the OEIDD [25], and the result is computed with a logarithm. The logarithm value is then used in the regression. The fourth control variable is the prior application year.

5. Results and discussions

5.1. Essential patents as a knowledge source

Comparisons among the business models' standard-based R&D are shown in Table 4, along with the coefficients and t-statistics of each variable. First, NPEs have positive effects and statistical significance at the 1% level in all regression models, indicating that more NPE inventions are based on essential patents than service providers' inventions. Thus, H1 is supported. Second, chipset vendors also have positive effects and statistical significance at the 1% level in all regression models, indicating that chipset vendors' inventions are based on essential patents. Thus, H2 is supported. On the other hand, manufacturers have a negative effect and statistical significance at the 1% level in regression model 3, while its coefficients in the other regression models are all positive and statistically significant at the 1% level. These results imply that essential patents are not as important for manufacturers' future R&D as they are for NPEs and chipset vendors but are more important for manufacturers' R&D than they are for service providers. As assumed in Section 3.3, a mobile standard as such may not be of much interest to manufacturers, and the coefficients of the following manufacturers (i.e., CN and KR) are neither consistent across the models nor statistically significant in any of them. Thus, the significance of mobile standards for the following manufacturers' R&D is not clear.

5.2. Internal knowledge as a knowledge source

Comparisons among the business models' internal knowledge-based R&D are shown in Table 5, along with the coefficients and t-statistics of each variable. In regression model 1, the coefficient of NPEs is negative and statistically significant at the 1% level in all regression models. Most of our NPE data come from InterDigital's patent applications. InterDigital declares all its essential patents [3], and the flow from its non-standard knowledge is very small. As a result, NPEs have almost no self-citation. Second, the coefficient of chipset vendors in regression model 2 is negative and statistically

Table 4
Regression result 1 DV: whether citing essential patents (=1) or not (=0).

	1	2	3	4	5	6	7	8	9
NPE	1.6382 [16.82]***				2.4949 [9.75]***	2.5487 [9.93]***	2.7526 [10.66]***	2.1236 [8.11]***	2.1108 [8.05]***
Chipset vendor		0.7036 [17.50]***			1.4724 [6.14]***	1.3946 [5.78]***	1.4277 [5.91]***	1.3128 [5.44]***	1.3076 [5.41]***
Manufacturer			−0.8006 [−21.20]***		0.9403 [4.02]***	0.8827 [3.76]***	0.9482 [4.04]***	0.6757 [2.88]***	0.6815 [2.90]***
Service provider				−0.9141 [−3.94]***					
China dummy					−0.3168 [−2.07]**	−0.3939 [−2.54]**	−0.1955 [−1.25]	0.5221 [3.22]***	0.49 [3.00]***
Japan dummy					−0.7378 [−14.38]***	−0.8677 [−13.03]***	−0.983 [−14.52]***	0.0089 [0.11]	0.0154 [0.19]
Korea dummy					0.0146 [0.26]	−0.1449 [−1.89]*	−0.2512 [−3.23]***	0.4157 [4.90]***	0.4091 [4.82]***
US dummy					0.0153 [0.30]	−0.0021 [−0.04]	0.0051 [0.10]	0.2702 [4.91]***	0.2742 [4.98]***
Log(NumPat)						0.1619 [3.02]***	0.1451 [2.71]***	−0.3586 [−6.34]***	−0.3659 [−6.45]***
RTA							−0.2172 [−8.77]***	−0.1917 [−7.42]***	−0.1896 [−7.33]***
Log(NumEssPat)								0.2702 [21.31]***	0.2720 [21.38]***
Application year	No	No	No	No	No	No	No	No	Yes
Constant	−1.7484 [−104.64]***	−1.8366 [−99.07]***	−1.0813 [−33.22]***	−1.7033 [−103.81]***	−2.6174 [−11.30]***	−3.1373 [−10.85]***	−2.9769 [−10.29]***	−2.9449 [−10.26]***	−25.6007 [−1.89]*
N	28801	28801	28801	28801	28801	28801	28801	28801	28801

significant at the 1% level, but the other coefficients in regression models 5–9 are not statistically significant. By contrast, manufacturers have positive effects with statistical significance at the 1% level in all regression models, indicating that manufacturers' inventions are based on their own technology, whereas following manufacturers do not tend to invent through their own technology. The coefficients of the China and Korea dummies are negative and statistically significant at the 1% level in all regression models, indicating that Chinese and Korean firms have not accumulated enough knowledge and thus rely on external knowledge rather than their own. This result is consistent with [32].

5.3. Results summary

We summarize the results in Table 6. Comparing Tables 1 and 6 shows that our assumption about the importance of future R&D based on standards is validated; however, the other knowledge sources are different. Our analysis indicates that internal

Table 5
Regression result 2 DV: whether citing patents filed by the same applicant (=1) or not (=0) (excluding essential patents in DV).

	1	2	3	4	5	6	7	8	9
NPE	−0.8857 [−7.84]***				−0.5256 [−3.07]***	−0.5 [−2.91]***	−0.5029 [−2.91]***	−0.7459 [−4.27]***	−0.8132 [−4.64]***
Chipset vendor		−0.4301 [−12.37]***			−0.0198 [−0.15]	−0.0591 [−0.44]	−0.0595 [−0.44]	−0.1027 [−0.76]	−0.1396 [−1.03]
Manufacturer			0.4934 [15.06]***		0.3497 [2.78]***	0.321 [2.53]**	0.3198 [2.52]**	0.2157 [1.70]*	0.24 [1.88]*
Service provider				−0.4101 [−3.30]***					
China dummy					−0.3316 [−3.02]***	−0.3789 [−3.37]***	−0.3825 [−3.37]***	−0.1724 [−1.48]	−0.3141 [−2.67]***
Japan dummy					0.5446 [16.90]***	0.4792 [10.51]***	0.4811 [10.35]***	0.8224 [14.45]***	0.8588 [15.03]***
Korea dummy					−0.3915 [−9.07]***	−0.4717 [−8.05]***	−0.47 [−7.95]***	−0.264 [−4.23]***	−0.2932 [−4.68]***
US dummy					0.0613 [1.60]	0.0525 [1.36]	0.0522 [1.35]	0.1507 [3.77]***	0.1809 [4.51]***
Log(NumPat)						0.0806 [2.02]**	0.0809 [2.03]**	−0.0729 [−1.72]*	−0.1072 [−2.51]**
RTA							0.0032 [0.21]	0.0224 [1.41]	0.0259 [1.63]
Log(NumEssPat)								0.1032 [10.46]***	0.1126 [11.35]***
Application year	No	No	No	No	No	No	No	No	Yes
Constant	−0.2751 [−22.95]***	−0.2256 [−17.56]***	−0.6983 [−23.23]***	−0.283 [−23.65]***	−0.6931 [−5.60]***	−0.9509 [−5.35]***	−0.9536 [−5.35]***	−1.0705 [−5.99]***	−102.42 [−10.57]***
N	28801	28801	28801	28801	28801	28801	28801	28801	28801

Table 6
Summary of the Regression Results: Each business model's reliance on the knowledge source.

	Standard	Internal knowledge
NPEs	Very high	Low
Chipset vendors	High	Low
Manufacturers	Medium	High
Service providers (base)	Low	Medium

knowledge is an important knowledge source for manufacturers but less important for NPEs and chipset vendors.

6. Conclusions and policy implications

This study examined the role of essential patents as a knowledge input for future R&D under W-CDMA and LTE. It divided essential patents-owning firms participating in standardization according to their business model and compared among their R&D activities based on essential patents as technological knowledge within a standard as well as their internal knowledge. The findings are as follows:

(1) Essential patents are much more important for NPEs' R&D than for that of any other business model, probably because the licensing fees expected from standard implementation and/or infringement constitute their revenue source. However, NPEs expend less R&D effort than do chipset vendors and manufacturers in terms of the number of patent applications, though their subsequent R&D is deeply rooted in essential patents.
(2) Essential patents are also more important for chipset vendors' R&D than for that of manufacturers and service providers. Their R&D efforts per firm, measured by the number of patent applications, are the highest in our data. Since mobile communication operations in chipsets are defined by technical standards, chipset vendors conduct their R&D based on essential patents.
(3) Essential patents are a more important knowledge source for manufacturers' R&D than for that of service providers but less important than for that of NPEs and chipset vendors. Manufacturers represent 72% (=31/43 * 100) of the firms owning essential patents and participating in standardization. They consider their internal knowledge more important as a source for future R&D than for essential patents. The question then remains why so many manufacturers participate in standardization while recognizing that essential patents as technological knowledge within a standard are not a knowledge source for future R&D. We address this question later in this section.

Our findings provide several implications. First, they provide a clue for the question posed in the introduction. This study empirically analyzes how firms participating in standardization use essential patents as standard-based knowledge for future R&D. It is well known that firms make great efforts to obtain essential patents [2–5,7–9]. However, our analysis shows that manufacturers' R&D, the biggest R&D share, is inactive when based on essential patents as technological knowledge within a standard. Amid their large volume of patents, their R&D seems not to be based on standards. We can thus conclude that manufacturers are interested only in obtaining essential patents. On the other hand, chipset vendors' R&D is based on standards, as seen in the volume of patents and the knowledge flowing from the standards. Thus, we can conclude that chipset vendors' interest is not limited to obtaining essential patents.

Second, our findings provide implications about NPEs. This study provides clear evidence that NPEs conduct R&D based on technical standards, though they made fewer patent applications than practicing companies did. Given their revenue source, implementing their own patented technologies is not in their interest. If their patents are related to technical standards and other business models' patents, NPEs' patents might worsen patent thickets [36] and hold-up problems [37]. Their patent portfolio may hamper the development of future standards. Since technical standards play a significant innovatory role in industries where the network effect is strong [11], delays in technical standard deployment must not be allowed.

Third, essential patents may be increasing tensions between firms. For example, essential patents are especially attractive to NPEs, whose main revenue source is licensing fees. These NPEs generate many standard-based inventions in order to obtain soon-to-be-standard and/or might-be-infringed-upon patents. Manufacturers must obtain essential patents before NPEs do. This tension produces a situation where manufacturers, despite striving to obtain essential patents through R&D and despite being the main implementers and largest party among essential patent owners, will not conduct additional R&D beyond the standard. Companies may be motivated to get essential patents in order 1) to have leverage over the standard [11,22], 2) to block competitors from privatizing the standard, or 3) to have an asset for cross-licensing and/or licensing revenue. Any one of these will inspire manufacturers to obtain essential patents, under the understanding that these results of technological knowledge within a technical standard will not be a knowledge source for future R&D. This tension wastes energy and resources and increases the social costs paid by customers.

Finally, this paper offers implications for countries with following manufacturers, such as China and Korea. This paper shows that Chinese and Korean companies depend little on their own knowledge, suggesting that their knowledge accumulation takes a long time and that they still rely on external knowledge from leading countries. Although knowledge transfer plays a key role in closing the gap between leaders and followers [39], China and Korea must strive to nurture the competitiveness of their domestic knowledge.

Finally, we would like to discuss this study's limitations. The first concerns the self-citations in regression 1. Firms cite their prior essential patents either for the next-generation standard or for the owner's own sake. The former case is dealt within our data construction. Recent studies [2,5,7–9] show that a patent rarely becomes essential by accident; rather, a patent aimed at a standard becomes essential through a firm's R&D and related activities. By dropping the patents filed by the standardization inventors, we dropped the self-citations intended for next-generation standards. Granted the latter case, moreover, a firm's intention cannot be proven through the data. For verification purposes, we performed the same analysis after dropping the self-citations in regression 1, with no significant difference seen in the results. Thus, citing essential patents for the owner's own sake is clearly trivial.

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Appendix A. Overview of correlations between independent variables in regressions.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. NPE	1										
2. Chipset vendors	−0.0517	1									
3. Manufacturers	−0.2708	−0.9101	1								
4. Service providers	−0.0126	−0.0423	−0.2218	1							
5. China dummy	−0.0049	−0.01	0.0141	−0.012	1						
6. Japan dummy	−0.077	−0.2589	0.2844	−0.0631	−0.0735	1					
7. Korea dummy	−0.0456	−0.1532	0.1684	−0.0373	−0.0435	−0.2285	1				
8. U.S. dummy	0.1822	0.6107	−0.6135	−0.0682	−0.0795	−0.4171	−0.2469	1			
9. Log (NumPat)	−0.2322	−0.1209	0.2278	−0.1488	0.0387	0.5098	0.433	−0.331	1		
10. RTA	0.1348	0.0391	−0.0781	−0.0078	0.1754	−0.2959	−0.1602	0.1807	−0.3102	1	
11. Log (NumEssPat)	0.0111	−0.078	0.079	−0.0352	−0.0471	−0.409	0.1305	−0.0242	−0.0334	0.0232	1

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