MMRC
DISCUSSION PAPER SERIES

No. 465

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January 2015

東京大学ものづくり経営研究センター
Manufacturing Management Research Center (MMRC)

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Investigating Firms' Knowledge Management in Standardization: The Analysis of the Networks of Technology Specifications and Declared Essential Patents on the Telecommunication Industry

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Abstract

Drawing on the case study of the telecommunication industry, we attempt to develop the debates on the condition to secure standard setters' competitive advantage under the diffusion of standardized technologies. Standardization helps standard setters profit from leading the industry while encouraging new competitors without sufficient knowledge to enter the industry to undermine standard setters' competitiveness. In such an environment, standard setters are required to conduct strategic knowledge management to secure their advantage. By conducting network and quantitative analyses on standard setters' technology specification and declared essential patent data, we found that leading standard setters built interrelated networks of various technology specifications and declared essential patents. The results showed that such leading standard setters did not separately pursue various fields of technology specifications and declared essential patents, but rather controlled the interdependencies between these fields of technology specifications and declared essential patents centering on a few critical technology fields. The results will help both academia and practitioners better understand how leading standard setters can manage their knowledge in face of standardization.

Key Words: knowledge management, standardization, appropriability, diffusion, networks, architectural (systemic) knowledge

1. Introduction

In many industries, leading firms as standard setters attempt to reflect their technologies on the industrial standards while collaborating with other standard setters based on the “consensus principle” to establish various technology specifications in consortiums (Sanders, 1972; Vernan, 1973; Katz and Shapiro, 1985; Farrell and Saloner, 1988). Setting technology specifications can help standard setters with sufficient proprietary knowledge not only enjoy the benefits from the standardization (e.g., market expansion, network externality, scale merit) but also lead the industry concerned (e.g., technological and time-based advantages).

However, setting technology specifications also induces non-standard setters without sufficient knowledge to enter the industry and enjoy the benefits of knowledge codification conducted by standard setters (West, 2003; Simcoe, Graham, Feldman, and Maryann, 2009). In such an environment, leading firms as standard setters are required to secure their advantages against non-standard setters by conducting strategic knowledge management for their standardization activities.

Standard setters are presumed to have two ways to secure their advantage: (1) protecting their advantages by exploiting their intellectual property rights tied up with standardization activities (e.g., Blind, Edler, Frietsch and Schmoch, 2006)[1] and (2) leading industrial technologies and product development by incorporating their technologies into standardized technology specifications (e.g., Funk, 2002; 2009). Antecedents primarily pay attention to the first way (1) suggesting that standard setters adopt patent strategies in accordance with different phases of standardization (Bekkers, 2001; Bekkers, Bongard and Nuvolari, 2009; Bekkers, Duysters and Verspagen, 2002; Bekkers and Liotard, 1999; Bekkers and Martinelli, 2010; Bekkers, Verspagen and Smits, 2002; Bekkers and West, 2006).

These studies regard patents as firms’ property rights to “appropriate” their technologies in standardization instead of discussing how standard setters should conduct their knowledge management in determining critical technology specifications in consideration of technology diffusion. As for the second way (2) regarding our main concern, standard setters will enable standardized technology specifications to work better on standard setters’ proprietary systems and thereby enjoy the advantage of product development faster than non-standard setters (Funk, 2002; 2009). In that case, standard setters can declare their patents to certain technology specifications under FRAND (Fair Reasonable And Non-Discriminatory) license terms in order to avoid non-standard setters’

[1] Patent strategies, securing the appropriability of technologies, can explain firms’ competitive advantages. As Granstrand, Patel and Pavitt (1997) mentioned, how diverse the overlap is between a firm’s patent portfolio can be regarded as a technology diversification, which bears the opportunities to introduce new technologies into products and systems for improved performance and new functionalities. It is still not well-known that how firms can pursue their technology diversification accompanying with standardization. We think that this is also an important future research topic for revealing how firms should acquire knowledge from standardization to diversify their technologies.

infringement on their proprietary knowledge.

Previous studies suggest that organizational capabilities to secure firms' competitiveness can be found in systemic knowledge management rather than the pile of technological elements (e.g., Clark and Fujimoto, 1991; Henderson and Cockburn, 1994; Henderson and Clark, 1990; Iansiti, 1997). Such a systemic perspective makes us infer that standard setters would attempt to manage the configuration of their diverse element technologies in harmony. Drawing on this perspective, this study sheds light on the "intra-firm" status and transition of standard setters' knowledge relevant to technology specifications with declared essential patents. In this study, we explore how standard setters orchestrate both technology specifications and declared essential patents by examining quantitative data on technology specifications and declared essential patents released from 3GPP (Third Generation Partnership Project), ETSI (European Telecommunications Standards Institute), and Espacenet (the database of the European Patent Office).

The study is constructed as following. First, we reviews antecedents related to the knowledge management of firms engaged in standardization in order to draw our research questions. Next, we develop the framework to show the research focus and the methodology to understand standard setters' knowledge management. Following these sections, we examine major standard setters' knowledge management by using the network analysis on the quantitative data of technology specifications and declared essential patents proposed by standard setters, and discuss the results. Lastly, the conclusion comes with the implications, limitations and future researches.

2. Survey

Standardization activities are known as an alignment mechanism in which firms negotiate with each other to decide the direction of technology development (Bekkers and Martinelli, 2010; Bekkers and Martinelli, 2012; Fontana, Nuvolari and Verspagen, 2009). In standardization, technology development tends to be incremental in nature and generally occurs around well-established technical designs in order that adequate levels of compatibility are maintained (Antonelli, 1992: p. 12). Once standardized product systems and/or technologies are well-accepted, any technology changes or improvements will reflect existing standardized technology specifications of these product systems and/or technologies (Leiponen, 2008; Leiponen and Bar, 2008).

Yet, in many cases, important aspects (i.e., connotations) of standard information are not clearly described in specific technology specifications but instead be written "between the lines" (Funk, 2002) and only well-understood through specific working groups of standardization activities. By contributing their efforts to standardization in a consortium, standard setters could acquire valuable technology information through working groups of standardization, which helps to complete product development faster than others (Funk, 2002; 2009). As Funk mentioned, firms attending standardization activities in a consortium can achieve high performances and stabilities within short development lead times by acquiring broader technology knowledge through the consortium. Thus, one of the most critical purposes of attending in standardization activities is to get information and knowledge regarding to technology changes on modified technology specifications earlier than other competitors.

However, we have to notice that there exist collaborative, non-competitive, interests as well as competitive interests in technology specification settings (Leiponen, 2008; Leiponen and Bar, 2008). Firms collaborate with each other to set technology specifications in order to achieve common benefits: typically market expansion through the diffusion of common standardized technologies. Since setting technology specifications induces knowledge codification which causes non-standard setters without sufficient knowledge to enter the industry concerned. Under such situation where new entrants can threaten standard setters, standard setters have incentives to declare their essential patents as intelligent property rights rewarding for their contributions to setting technology specifications. Leiponen (2008) and Leiponen and Bar (2008) indicate that it is important for standard setters to embed themselves into superior alliance networks so that their patents can be incorporated into technology specifications. Also Bekkers, Bongard and Nuvolari (2009), echoed with Leiponen (2008) and Leiponen and Bar (2008), reveal that both the technological significance of patents and applicant involvement in standardization process have positive effects on the probability that the patents can be claimed as essential.

In the sense, the interrelationship between technology specifications and declared essential patents should be considered with regard to standard setters' participation in standardization activities (Blind and Thumm, 2004). In the line of studies, firms' patent strategies in standardization are regarded as critical parts of their knowledge management. Many studies presume that standard setters' patent strategies aim to "appropriate" their technologies to themselves in order to preserve their rights to reward for their contributions to the standardization (Bekkers and Liotard, 1999; Bekkers, 2001; Bekkers, Duysters and Verspagen, 2002; Bekkers, Verspagen and Smits, 2002; Bekkers and West, 2006; 2009; Bekkers, Bongard and Nuvolari, 2009; Bekkers and Martinelli, 2010; Bekkers and Martinelli, 2012; Garrard, 1998; Granstrand, 1999; He, Lim and Wong, 2006). Relying on the presumption, past studies primarily pay attention to firms' behaviors regarding patents, particularly focusing on how to extract most benefits from their scope of patents (Blind, Edler, Frietsch and Schmoch, 2006; Hall and Ziedonis, 2001). However, standard setters face the dilemma between the advantages by the appropriability of technologies and the benefits from the diffusion by the standardization of technologies (Blind and Thumm, 2004; Simcoe, Graham, Feldman, and Maryann, 2009; West, 2003). The inner logic, more specifically intra-firm knowledge statuses and transitions, of standard setters to cope with the dilemma is still blurred. In other words, it is less known how firms should conduct knowledge management for sustaining their advantages while participating in standardization activities.

The dilemma for standard setters poses a question on standard setters' knowledge management: how standard setters can sustain their competitive advantage in knowledge management in spite of the diffusion of their knowledge, as codified knowledge, through standardization. The explanation to the question is expected to elucidate standard setters' knowledge management to cope with technology specifications while appropriating their property rights to themselves in standardization.

3. Framework and Focus

In this section, we propose our framework and research focus defining the characteristics of knowledge relevant to standardization. It is known that firms' knowledge management needs to take the different periods of standardization into account (Van de Ven and Garud, 1994; Rosenkopf and Tushman, 1998). In the pre-standard discussion phase, firms are required to establish general knowledge regarding to the principle characteristics of the product system concerned. In standardization phase, it is necessary for firms to construct their specific knowledge in accordance with different types of detailed technology specifications (Bekkers and Liotard, 1999; Granstrand, 1999, p. 204; Bekkers, Duysters and Verspagen, 2002; Bekkers, Verspagen and Smits, 2002).

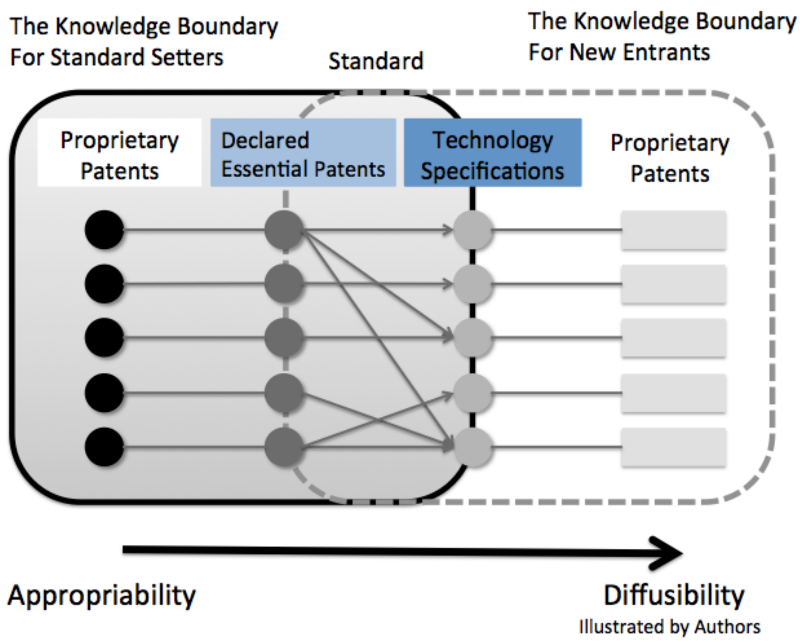
Particularly in the development of CoPS (Complex Product Systems), like telecommunication system (Davies, 1996; Davies, 1999; Davies and Brady, 2000; Miller, Hobday, Leroux-Demers and Olleros, 1995; Hobday, 1995; Hobday, 1998; Hobday, 2001), firms need to integrate and combine different domains of knowledge (Brusoni and Precipe, 2001; Brusoni, Precipe and Pavitt, 2001) through specific "integrated problem-solving" (Nelson and Winter, 1982; Tushman and Anderson, 1987; Christensen, 1997). According to such a nature of the development of CoPS, standard setters in standardization are presumed to integrate diverse knowledge, which is dispersed across "technology specifications" and "declared essential patents," resting on systemic knowledge specific to standard setters. Firms' competitiveness can be secured by their architectural, systemic, knowledge rather than element technologies such as patents (Henderson and Clark, 1990; Henderson and Cockburn, 1994). Therefore, standard setters are expected to build their advantages with systemic knowledge to deal with complex technological interdependences and compatibilities faster than others (i.e., non-standard setters).

Drawing on this systemic perspective, this study examines standard setters' knowledge management by understanding the statuses and transitions of the interdependencies between "technology specifications" and "declared essential patents," which are considered as the operational variables of knowledge in past studies on standard-related patent strategies. It is widely recognized that patents are taken for granted for protecting participants' rights rewarding for their contributions to standardization. Patents, essential patents, declared for technology specifications are called SEPs (Standard Essential Patents). SEPs are based on FRAND (Fair, Reasonable, And Non-Discriminatory) license terms to give rights to standard setters to prevent non-standard setters from infringing (i.e., free-riding) on standard setters' rights (e.g., illegal production, sell, import, use and/or operation of products).

Yet, as shown in Figure 1, when firms participate in standardization, there have two different knowledge boundaries which should be taken into account. The left side interprets standard setters' proprietary knowledge domain, which includes "proprietary patents (i.e., patents published through country patent offices)," "declared essential patents" and "technology specifications." On the contrary, the right side represents standardized knowledge, composed by "proprietary patents," "technology specifications" and "declared essential patents," which allow non-standard setters to acquire knowledge necessary for their product developments based on the standard.

Figure 1. Relationships between Declared Essential Patents and

Technology Specifications in Firms' Knowledge



The intersection part between standard setters' and non-standard setters' knowledge boundaries is created by standard setters in standardization. In this intersection part, standard setters are involved in standardization activities to create technology specifications for diffusing their technologies while declaring their essential patents relevant to those technology specifications against non-standard setters' infringement on their knowledge. It is vital for standard setters to conduct their patent portfolios compatible to diffusible technology specifications in the product system concerned (Carlsson and Stankiewicz, 1999). The interdependencies between technology specifications and declared essential patents in each of standard setters are presumed to indicate the statuses of systemic knowledge to bridge between the appropriability and diffusibility of standard setters' knowledge. Such interdependencies will help us explicate standard setters' knowledge management in standardization.

Therefore, we take the networks of technology specification and declared essential patents as an interdependent interfaces of two knowledge boundaries which standard setters need to focus on. In particular, the more complex a product system is, the more difficult it is for standard setters to set essential patents corresponding to technology specifications in the manner of one-to-one relationships. That means, particularly in the case of CoPS, standard setters are required to deal with highly interdependent relationships between technology specifications and declared essential patents. Otherwise, standard setters can neither make their product systems acceptable in the market by well-defined technology specifications nor consolidate their advantages of product development prior to non-standard setters.

4. Methodology and Data

The standardization in the telecommunication industry can be a proper case to elucidate standard setters' knowledge management to sustain their advantages of product development. As used in many previous studies (e.g., Bekkers and Liotard, 1999; Bekkers, Duysters and Verspagen, 2002; Bekkers, Verspagen and Smits, 2002), the data of technology specifications and declared essential patents in the telecommunication industry are officially provided in a reliable manner (as described later). Thus, this study takes the 3GPP standardization as an informative case for the quantitative and qualitative study to explore the networks of technology specification and declared essential patents.

In the telecommunication industry, 3GPP was spun out of ETSI in 1998 and began operations in 2000, inherited most of its operating procedures from ETSI and, as a result, retained their approach to open membership, intellectual property provisions, committee structure, and working procedures. Since most standard setters which had developed their own 2G GSM products decided to continue choosing the 3G UMTS technologies to develop their products, it is reasonable for them to concentrate on 3GPP. Yet, we exclude the 3GPP2 standardization in our analysis. This is because that 3GPP2 was mainly initiated and managed by Qualcomm, which aimed at the standardization for 3G CDMA2000.

Our study used technology specifications and declared essential patents as proxy variables to depict standard setters' standardization activities in terms of their knowledge management. Because these technology specifications and declared essential patents contain many technical descriptions, we first started understanding these information from a systematic review of technical literatures, trade publications, specialized engineering journals, company annual reports and publications. These data providing background information were used to sketch the overall picture of the sectors analyzed in this study. We also conducted many semi-structured interviews to acquire qualitative insights for understanding the importance of standard setters' knowledge management interplaying between technology specifications and declared essential patents in the telecommunication industry.

Afterwards, we downloaded the technology specification database from the 3GPP website on 20 December, 2009[2]. This database contains 6,243 "Technology Specifications" and 112,386 "Change Requests" from 15 April, 1988 to December, 2009[3]. In order to keep the reliability and conformity of the database, we also wrote an email to confirm with John M Meredith, the 3GPP Specifications Manager, ETSI, that this database did contain all the technology specifications and change requests for the time periods above[4].

The 3GPP technology specification database has its specific format. Therefore, we also referred to the "Third Generation Partnership Project: 3GPP Working Procedures"[5] and the "3GPP TR 21.900 V7.2.0 (2006-06)[6]" to clarify the process of technology standardization and deal with the 3GPP specification database. The most valuable variable in this database is the data of "rapporteurs" that can help clarify who the authors of technology specifications are[7]. Moreover, rapporteurs receive change requests and maintain the level of completion and stability of technology specifications. Finally, we found there were 50 and 87 companies attended respectively in the 2G GSM and 3G UMTS standardizations[8].

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[2] Source from: http://www.3gpp.org/ftp/Information/Databases/Spec_Status/3GPP-Spec-Status.zip

[3] In our research, we grouped 2G GSM, 2.5G GPRS and 2.75G Edge into "2G GSM" and 3G UMTS, 3.5G HSDPA and 3.75G HSUPA into "3G UMTS" for more reasonable calculation.

[4] The reply of John M. Meredith was "Releases up to Rel-8 are complete, other than for essential corrections (still quite a lot in the case of the most recent Release, Rel-8). Release 9 is still under development, and most of its specs will not be created until after the freeze date, currently envisaged as December 2009. Release 10 development has only just begun. By the way, take no notice of the Release called "UMTS"; this was the early investigation work done on the 3rd Generation system by ETSI TC SMG between 1992 and 1998. All those documents are effectively archived. The status data is completely up to date. The date named in the file "2001-11-28_flat-table-for-flat-earthers" is the date the queries were written, and are named thus for cataloguing purposes. That date has nothing to do with the date of the data contained in those tables, which is as fresh as the timestamp on the dbf file !"

[5] Downloaded from http://www.3gpp.org/ftp/Information/Working_Procedures/3GPP_WP.pdf

[6] Downloaded from http://www.qtc.jp/3GPP/Specs/21900-720.pdf

[7] We also grouped a firm and its affiliates into one company for the purpose of calculation. For example, we put Nokia UK Ltd, Nokia Siemens Networks, Nokia Corporation, Nokia Japan Ltd, Nokia Mobile Phones, Nokia Research Center, Nokia Communications, and Nokia Telecommunication Inc. into "Nokia."

[8] The kurtosis and skewness in the described statistics signify that both the 2G and the 3G technology standardizations

In order to precisely clarify how each firm's technology specifications were positioned in terms of the architecture of telecommunication system, we interviewed 5 software engineers and 7 hardware engineers from one of the Taiwanese mobile phone ODM, so that we could categorize technology specifications with 5 levels represented as "Service and Technical Issues, Requirements and Plans," "Core Network and Intra Fixed Network," "Air Interface," "Mobile Phone" and "Security Algorithm" (Table 1). When a technology specification covered two or multi levels, we asked the interviewees to decide which level was the most suitable for the technology specification concerned.

Table 1 Technology Specifications Categorized by Architecture of Telecommunication System

Levels	Specification Categories	2G series	3G series
Service & Technical Issues, Requirements and Plans	"Requirements" , "Service aspects ("stage 1")" , "Technical realization ("stage 2")" , "Programme management" , "LTE (Evolved UTRA) and LTE-Advanced radio technolgy" , "General information (long defunct)".	00,01,02,03,10 ,41,42,43,50,	21,22,23,30,36
Switching Station / Core Network and Intra Fixed Network	"Signalling protocols ("stage 3") -(RSS-CN)" , "Signalling protocols ("stage 3") - intra-fixed-network" .	08,09,48,49	28,29
Base Station / Base Station / Air Interface	"Signalling protocols ("stage 3") - user equipment to network" , "Radio aspects" , "CODECs" , "Data" , "OAM&P and Charging" , "Multiple radio access technology aspects".	04,05,06,07,12 ,44,45,46,52	24,25,26,27,32 ,37
Mobile Phone / Mobile Phone / Mobile Phone / Mobile Phone	"Subscriber Identity Module (SIM / USIM), IC Cards. Test specs" , "UE and (U)SIM test specifications".	11,51	31,34
Security Algorithms	"Security aspects" , "Security algorithms (3)".	55	33,35

(Source from http://www.3gpp.org/specifications/specification-numbering, categorized by authors)

First, we used change requests of 3GPP to reveal how frequently technology specifications were changing from the 2G GSM to the 3G UMTS standardizations. In the sense, we further inferred which standard setters contributed more efforts to which parts of technology specifications of telecommunication system. According to "Categories of Change Requests on P.16 of 3GPP TR 21.900 V7.2.0 (2006-06)," there were the A, B, C, D, E and F categories of change requests[9]. We only chose change requests belonging to the B and C categories for our analysis. This is because the B category represents new technology functions updated and the C category represents existing technology functions modified, respectively. Finally, we excluded 4,282 unclear change requests and

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were controlled by certain companies. That is to say, in the technology standardization, the top 5 companies in the field owned 59.55% and 61.84% of the totals of the 2G and 3G technology standards, respectively.

[9] The E category had not been used, the A category was used for modifying and updating pre-version technology specifications, and the D and F categories were used to modify typo mistakes of existing documents.

those change requests belonging to the E category, and obtained 108,104 available change requests for our analysis. Afterwards, we analyzed the 2G GSM and 3G UMTS technology specifications to understand which standard setters had which sorts of knowledge corresponding to various technology specifications categorized by the architectural of telecommunication system.

Next, we also downloaded the worldwide declared essential patent database from the ETSI website in December, 2012[10]. This database contained 64,228 declared essential patents from 1990 to 2012. Then, we integrated the worldwide declared essential patent database with technology specification database, and thereby mapped each of those declared essential patents toward every technology specification, correspondingly. Then, we examined how the relationships between declared essential patents and technology specifications were. In other words, by using the architecture of telecommunication system defined previously, we attempted to understand how those declared essential patents held by a particular standard setter were related to different technology specifications, or how those declared essential patents were only related to those technology specifications belonging to the same technology specification categories.

For this purpose, we used network analysis software: UCInet and its function, called "Affiliations: Convert 2-mode to 1-mode data," to extract interdependent relationships between various technology specifications which were connected by declared essential patents. Afterwards, we highlighted this interdependent relationships in leading standard setters by the U.S. and European data to see how standard setters conducted their patent strategies while setting technology specifications for the accumulated periods of every 5 years. The External-Internal index (Krackhardt and Stern, 1988) was also adopted to know how standard setters intensively declared their essential patents with various technology specifications in terms of the architecture of telecommunication system.

5. Case Study

5.1. Sustaining Innovation in the Telecommunication Industry

The telecommunication industry is a relatively new industry. The first commercial mobile phone emerged circa 1985, and the demand and production started increasing exponentially since the early 1990 (Alcacer and Oxley, 2014). Since 1996, more than 50% of the product system market (i.e., telecommunication infrastructure and mobile phone) had been dominated by Nokia, Ericsson, and Motorola (Table 2). In 2010, Nokia, Ericsson, Motorola, Siemens, and Alcatel still accounted for more than 80 percent of the global mobile phone sales (Alcacer and Oxley, 2014). As Funk (2002) and Funk (2009) assert, the success of Nokia, Ericsson and Motorola in the infrastructure and mobile phone business markets relied on their attendance in the standardization activities. By setting

[10] Downloaded from http://ipr.etsi.org/searchIPRD.aspx

technology specifications for a long period of the standardization, Nokia, Ericsson and Motorola should have accumulated a wide range of technology knowledge compared to non-standard setters. Thus, such knowledge is presumed to enable these leading standard setters to develop their infrastructure and mobile phone developments continuously prior to their competitors.

Table 2 Firms' Worldwide Market Share in Infrastructure and Mobile Phone (1996~2007)

	Infrastructure				Mobile Phone											
	Core Network (+)	Base Station (+)	Core Network And Base Station													
	1996	1996	1997	1998	1996	1997	1998	1999	2000	2001(*)	2002(*)	2003(*)	2004	2005	2006	2007
Nokia	14	22	10	12	24	20	22.5	26.9	30.6	35	35.8	34.7	32.8	33.2	33.6	37.0
Ericsson	48	37	30	29	25	16	15.1	10.5	10.1	6.7(**)	6.7(**)	5.1(**)	6.7 (**)	6.4 (**)	7.1 (**)	9 (**)
Motorola	1	13	15	12	20	25	19.5	16.9	14.5	14.8	15.3	14.5	16.6	18.3	21	13.0
Lucent	2	4	13	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NEC	N/A	N/A	5	5	N/A	5	4.2	3.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Siemens	21	2	5	5	9	3.6	2.9	4.6	6.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nortel	1	0	13	11	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Alcatel	10	10	4	4	6	2.5	4.3	4.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Panasonic	N/A	N/A	N/A	N/A	N/A	7.3	8.2	5.4	5.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mitsubishi	N/A	N/A	N/A	N/A	N/A	3	2.8	3.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ZTE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.4
Samsung	N/A	N/A	N/A	N/A	N/A	N/A	2.7	6.2	5.2	7.1	9.8	10.5	13.9	13.1	11.5	14.0
Others	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	23	22.1	20.5	N/A
LG	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	7	6.9	6.3	7.0

(+): Core network and base station market share in Europe.
Source : Infrastructure (1997~1998) and mobile phone market share (1997~1999) are quoted from Funk (2002). Funk (2002) collected these data from DataQuest's Gartner Group (2000), Nokia extends head in cell-phone market, Dataquest says, *Bloomberg News*, February 8, 2000. Infrastructure market share in Europe and worldwide mobile phone market share in 1996 are quoted from Bekkers and Liotard (1999). Mobile phone market share (2000) is quoted from 中國信託科技產業推展中心,2001年12月 (https://www.chinatrust.com.tw/enterprise/report/mobile_phone.pdf).
Source: the data from 2001 to 2007 is from company data, MIC, Nov 2007; He, Lim and Wong(2006) for 2001(*), 2002(*), 2003(*). Starting from 1Q06, the "Others" includes the share of China white brand mobile phone manufacturers (He, Lim and Wong, 2006). ** represents Sony Ericsson

It is widely known that telecommunication systems composited by infrastructures and mobile phones are CoPS (Davies, 1996; Davies, 1999; Davies and Brady, 2000; Miller, Hobday, Leroux-Demers and Olleros, 1995; Hobday, 1995; Hobday, 1998; Hobday, 2001), which requires technology specifications to lower the complexity of the technology development of telecommunication system. ETSI, formed by European Commission in 1987, aimed to help CEPT (Committee on European Postal Regulations), which favored operators, speed up the 2G GSM technology standardization from 1988 to 1991. 3GPP, as the central standard body, was in charge of coordinating other standard bodies to implement the 3G UMTS standardization since 1998[11].

The "Cellular Architecture" has been known as the dominant design that defines how infrastructure interacts complicatedly with various mobile phones through multiple cellular signal

[11] 3GPP cooperates with standard bodies of other countries to work on the 3GPP partnership project for implementing the same technologies and speeding up service adoption. In addition to the European standard body ETSI, there are also other standard bodies in different countries, such as ARIB (Association for Radio Industries and Businesses) and TTC (Telecommunication Technology Committee) of Japan, CWTS (China Wireless Telecommunication Standard) of China, T1 (Standards Committee T1 - Telecommunications) of U.S., and TTA (Telecommunications Technology Association) of Korea, in charge of the 3G UMTS standardization.

areas (Davies, 1996; Steinbock, 2002)[12]. Because the standardization of 2G GSM and 3G UMTS shared the same "Cellular Architecture," the core concept of the telecommunication system (Davies, 1996; Steinbock, 2002), standard setters created technology specifications at the early stage of standardization could easily apply their knowledge to the continuous technological improvements of the telecommunication system at the latter stage of standardization.

Regarding to this concern, we found that in 6,243 technology specifications published by 3GPP from 15 April, 1988 to December, 2009, approximately 46.55 % of the 3G UMTS technology specifications were derived from the 2G GSM technology specifications[13]. This finding requires us to examine whether leading standard setters, Nokia, Ericsson and Motorola, also leveraged their existing technology specifications to create new technology specifications for the long period of the standardization. If so, regardless of their strategic intentions, Nokia, Ericsson and Motorola were supposed to conduct their "knowledge management" with enhancing their knowledge base continuously in the standardization.

Observing the technology change of the telecommunication system also provides us an opportunity to understand what sorts of knowledge were required for the knowledge management of Nokia, Ericsson and Motorola. In respect of the extent of technology changes from 15 April, 1988 to December of 2009 in the telecommunication industry, this study used 112,236 change requests of 6,243 technology specifications and classified these change requests into the 5 levels of the telecommunication system: "Service & Technical Issues, Requirements and Plans," "Core Network and Intra Fixed Network," "Air Interface," "Mobile Phone" and "Security Algorithm." [14] As shown in

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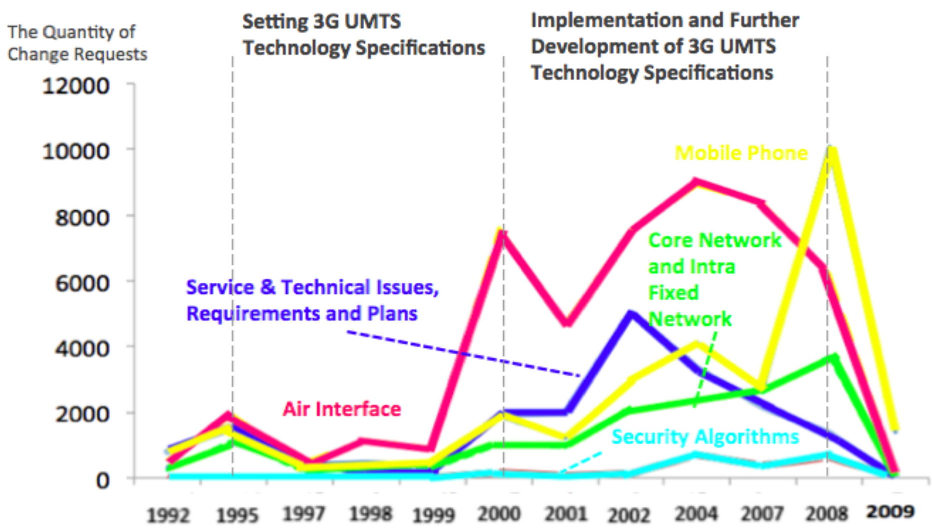
[12] Compared to 2G GSM, 3G UMTS uses higher frequency bands and more state-of-the-art wireless access technologies to increase its network capacity and allows more simultaneous calls. In particular, the 3G UMTS technology reduces the failures of dropped calls when users are moving from one place to another by cars or trains. In addition, the high-speed data download capability is another advantage of 3G UMTS. The notion of the 3G UMTS technology has shifted telecommunication from voice communication to "mobile internet" or "broadband wireless," which expands the range of mobile communication services from voice data to package data in terms of always-online-always-connected.

[13] We referred the "3GPP TR 21.900 V7.2.0 (2006-06), P.9 Table 2: Specification number ranges bbb" to caculate this number.

[14] According to "Categories of Change Requests on P.16 of 3GPP TR 21.900 V7.2.0 (2006-06)", there are the A, B, C, D, E and F categories of change requests. The E category is not used, the A category is used for modifying and updating pre-version technology standards, and the D and F categories are used to modify typo mistakes of existing documents. We chose to use the B and C categories to analyze change requests because the B category represents new functions updated and the C category represents "technology modification and new features." The percentages of change requests relevant to "technology modification and new features" of a total change requests, in accordance with the 5 levels of telecommunication system, are 28.29%, 26.71%, 18.45%, 9.77%, and 0% respectively for the 2G GSM "Service & Technical Issues, Requirements and Plans," "Core Network and Intra Fixed Network," "Air Interface,"

Figure 2, in addition to the change requests of "Air Interface[15]," the change requests related to the other 4 levels of the telecommunication system all increased, which accompanied the releases of technology specifications (e.g., the period of implementation and further development of 3G UMTS technology specifications) even after the stage of technology specifications were established (e.g., the period of setting the 3G UMTS technology specifications)[16].

Figure 2 Change Requests of Technology Specifications



(Source from http://www.3gpp.org, analyzed by authors)

Combined with the previous findings (i.e., about 46.55 % of the 3G UMTS technology specifications were derived from 2G GSM technology specifications), the data in Figure 2 indicates that technology development of the telecommunication system requires standard setters to pay attention to dynamically changing technology specifications of existing technologies including all the

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"Mobile Phone" and "Security Algorithm." and 26.09%, 21.74%, 17.56%, 11.70% and 27.48% respectively for each level of the 3G UMTS telecommunication system. These numbers mean that standard setters need to deal with change requests relative to "technology modification and new features" for their product developments.

[15] Even though the ratios of change requests related to technology modification and new features of total the 2G GSM and 3G UMTS change requests on "Air Interface" are not as high as the ratios on other levels respectively, standard setters need to pay much attention to this level.

[16] Figure 2 shows that the number of change requests has decreased since 2008. This is because that at the timing of the data download on 20, December 2009, the 3G UMTS technology standardization was almost completed in "Release 8 (i.e., technology specifications)" released in 2008 while the 4G LTE technology standardization started. Moreover, we referred Bekkers and West (2009, p.87) to illustrate the periods of "setting the 3G UMTS technology specifications" and "the implementation and further development of the 3G UMTS technology specifications."

5 levels of the telecommunication system. In other words, our data implies that standard setters' technology developments are sustaining innovations. In such a circumstance, creating a wide range of technology specifications can become inevitable for standard setters which attempt to establish competitive advantage in accommodating to technology changes caused by change requests. Therefore, the knowledge management of leading standard setters, such as Nokia, Ericsson and Motorola, is presumed to cover all the 5 levels of telecommunication system and thus enhance their knowledge bases for sustaining their advantages of infrastructure and mobile phone developments for the long period of the standardization.

5.2. Standard Setters' Knowledge Base and Its Derivations

This section attempts to reveal the sorts of knowledge that standard setters have in the 2G GSM and 3G UMTS telecommunication systems. First, we found that 6,243 technology specifications were created by 50 and 87 companies respectively in the 2G GSM and 3G UMTS standardizations. Moreover, it is approximated that 59.55% and 61.84% of the totals of the 2G and 3G technology specifications were created by top 5 standard setters. As shown in Table 3, first, we noticed that as for the quantity of standard setters' 2G GSM technology specifications, Nokia, Ericsson and Motorola were each ranked as number 1 (370 pieces), number 4 (104 pieces), and number 6 (94 pieces) among 50 firms. As for the quantity of standard setters' 3G UMTS technology specifications, Nokia, Ericsson and Motorola were each ranked as number 1 (808 pieces), number 2 (612 pieces), number 11 (81 pieces) among 87 firms[17].

[17] We also notice that the quantity of Qualcomm's 2G GSM technology specifications was 317, which was next to Nokia's. However, Qualcomm's 3G UMTS technology specifications were only 94, which were less than Nokia's and Ericsson's but similar to the quantity of Motorola's 3G UMTS technology specifications. Moreover, it is worth noticing that the Chinese telecommunication equipment and mobile phone manufacturers, Huawei and China Mobile, were the 4th and 7th amongst firms contributing to the 3G technology specifications.

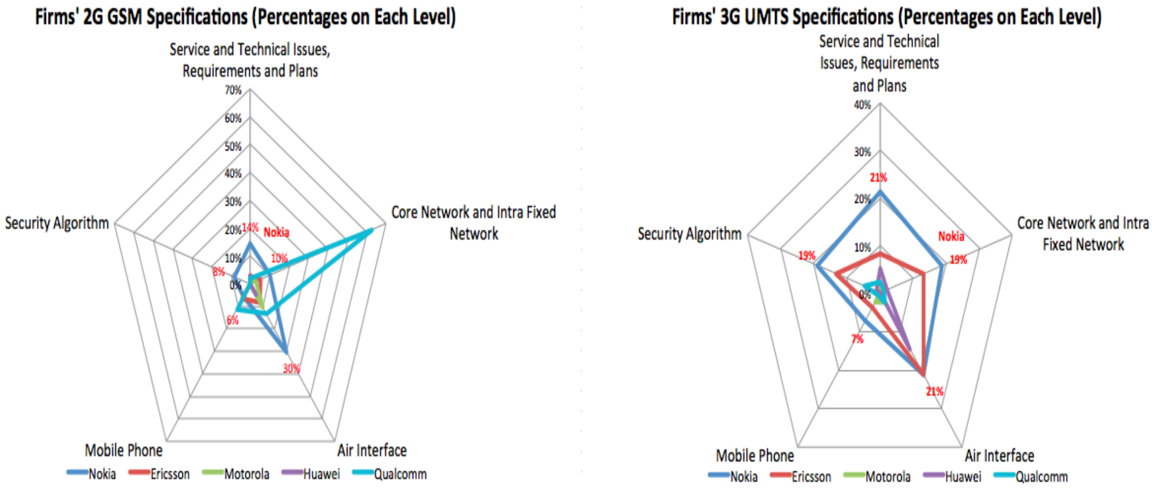
Table 3 Top 14 2G GSM And 3G UMTS Standard Setters (Judged By Technology Specifications)

Rank	2G GSM Technology Specification		3G UMTS Technology Specification		2G GSM and 3G UMTS Technology Specification	
	Standard Setter	Technology Specifications	Standard Setter	Technology Specifications	Standard Setter	Technology Specifications
1	Nokia	370	Nokia	808	Nokia	1178
2	Qualcomm	317	Ericsson	612	Ericsson	716
3	ETSI	238	Alcatel-Lucent	377	Huawei	423
4	Ericsson	104	Huawei	366	Qualcomm	411
5	RIM	97	Vodafone	303	ETSI	393
6	Motorola	94	ETSI	155	Alcatel-Lucent	392
7	Vodafone	81	China Mobile Com. Corporation	103	Vodafone	384
8	SOURCE COM	77	NEC	96	RIM	189
9	KTF	72	Qualcomm	94	Motorola	175
10	Nortel	71	RIM	92	SOURCE COM	119
11	Huawei	57	Motorola	81	Deutsche Telekom AG	114
12	Deutsche Telekom AG	36	Deutsche Telekom AG	78	Nortel	107
13	France Telecom	34	DoCoMo	61	NEC	107
14	Gemalto N.V.	27	T-Mobile	46	China Mobile Com. Corporation	104
Notices	Others (36 Firms)	216	Others (73 Firms)	716	Others (95 Firms)	1067
	Unknown Firm Name Specs	192	Unknown Firm Name Specs	166	Unknown Firm Name Specs	358
					Unknown Series Specs	6
	Total	2083	Total	4154	Total	6243
	Specifications are classified into 2G and 3G by specification numbering of 3GPP (http://www.3gpp.org/specification-numbering). 3G and beyond / GSM (R99 and later) include 21-37 series; GSM only (Rel-4 and later) include 41-46, 48-52 and 55series; GSM only (before Rel-4) include 00-12 series. Source download from http://www.3gpp.org/ftp/Information/Databases/Spec_Status/3GPP-Spec-Status.zip, 2009/12/20. The database contains 6243 2G and 3G specifications (Technical Specification and Technical Report) which started from 1988/4/15 to 2009/12.					

Second, we further examined these firms' quantity of technology specifications compared to the total technology specifications at each level of the telecommunication system. For example, Nokia had 102 of the 2G GSM and 251 of the 3G UMTS technology specifications of the "Service & Technical Issues, Requirements and Plans" level out of the total of 707 and 1,182 respectively for the 2G GSM and 3G UMTS. Nokia owned 14% and 21% of the total 2G GSM and 3G UMTS technology specifications at the "Service & Technical Issues, Requirements and Plans" level. Following this calculation, Figure 3 shows that Nokia had its certain percentage of technology specifications at each level of the 2G GSM and 3G UMTS telecommunication system, which means that Nokia was the firm who created the broadest knowledge base of telecommunication system by aggressively setting technology specifications among the top 14 firms. Similarly, Ericsson created broad knowledge base through setting the 3G UMTS technology specifications compared to its activities in setting the 2G GSM technology specifications. Motorola had less significant knowledge base through setting both the 2G GSM and 3G UMTS technology specifications. Surprisingly, Qualcomm created broad knowledge base. In particular, the share of its technology knowledge related to "Core Network and Infra Fixed Network" was approximated to 63% at this level, compared to its activities in setting the 3G UMTS technology specifications. The data here combined with previous findings shows that Nokia, Ericsson and Motorola had created a wide range of knowledge base related to the whole telecommunication system through creating the 2G GSM and 3G UMTS technology specifications.

Figure 3 Leading Standard Setters' 2G GSM and 3G UMTS Technology Specifications

(Percentages on Each Level of Telecommunication System)



(Source from http://www.3gpp.org, analyzed by authors)

Third, we counted the number of re-versions of technology specifications to reveal how standard setters sustain their knowledge bases for a long period. We used the re-versions of technology specifications to represent the deviations of standard setters' knowledge bases. Once the change requests are acknowledged at the relevant committees, then a new version is filed following the original technology specifications. Consequently, some particular technology specifications are, or will be, modified and updated for the next version releases of corresponding technology specifications. For example, Nokia's TS 02.16 "International Mobile Station Equipment Identities (IMEI)" has been re-versioned into the Phase 1, Phase 2, Release 97, and Release 98 of technology specifications.

As shown in Table 4, 6,243 of the 2G GSM and 3G UMTS technology specifications were derived from 2,248 common technology specifications. In other words, on average, 36% of technology specifications could be derived from one single technology specification. In particular, the derivations of technology specifications of Nokia, Ericsson, Motorola were 33%, 37% and 37% respectively, which means that Nokia, Ericsson, and Motorola sustained their knowledge bases underlying original technology specifications to create new technology specifications in terms of more advanced technology development. In summary, combined with previous findings, our data shows that the knowledge management of Nokia, Ericsson and Motorola covered all the 5 levels of telecommunication system, and had continuously sustained their knowledge bases for developing infrastructures and mobile phones for the long period of the standardization.

Table 4 Firms' Derivation of Technology Specifications

Firms	Total Technology Specifications	The Amounts of Technology Specifications Used in Different Release	(The Amounts of Technology Specifications Used in Different Release / Total Technology Specifications, %)
Nokia	1178	387	33%
Ericsson	716	263	37%
Huawei	423	154	36%
Qualcomm	411	106	26%
ETSI	393	127	32%
Alcatel-Lucent	392	149	38%
Vodafone	384	128	33%
RIM	189	44	23%
Motorola	175	64	37%
SOURCE COM	119	31	26%
Deutsche Telekom AG	114	39	34%
Nortel	107	41	38%
NEC	107	30	28%
China Mobile	104	57	55%
Total	6237 (only excluding Unknown Series Specs)	2248	36%

(Source from http://www.3gpp.org, analyzed by authors)

5.3. The Appropriability of Standard Setters' Knowledge

In this section, we attempt to reveal how leading standard setters, Nokia, Ericsson and Motorola, prevented other competitors from their infringement (i.e., free-riding) on standard setters' advantages of proprietary knowledge in the standardization. Here, in order to show firms' declared essential patent strategies in accordance with their standardization activities for the 5 levels of telecommunication system, we used the data of 64,228 essential patents which were declared to ETSI from 1990 to 2012, and combined the data with the database of technology specifications. Any firm can declare their patents published in any countries as the essential patents of 3GPP. Thus, we filtered out those declared essential patents which were only published at the U.S. and Europe patent offices[18]as the U.S. and Europe are two of the most competitive telecommunication markets in the world. Standard setters' declared essential patents can be regarded as property rights to protect their advantages under FRAND license terms against products sold in these markets without permissions or licenses from standard setters,.

Figure 4 shows the most representative standard setters' positions (as also used in Table 4) corresponding to the quantities of the 2G GSM and 3G UMTS technology specification settings and their declared essential patents published at the U.S and European patent offices[19]. Standard setters

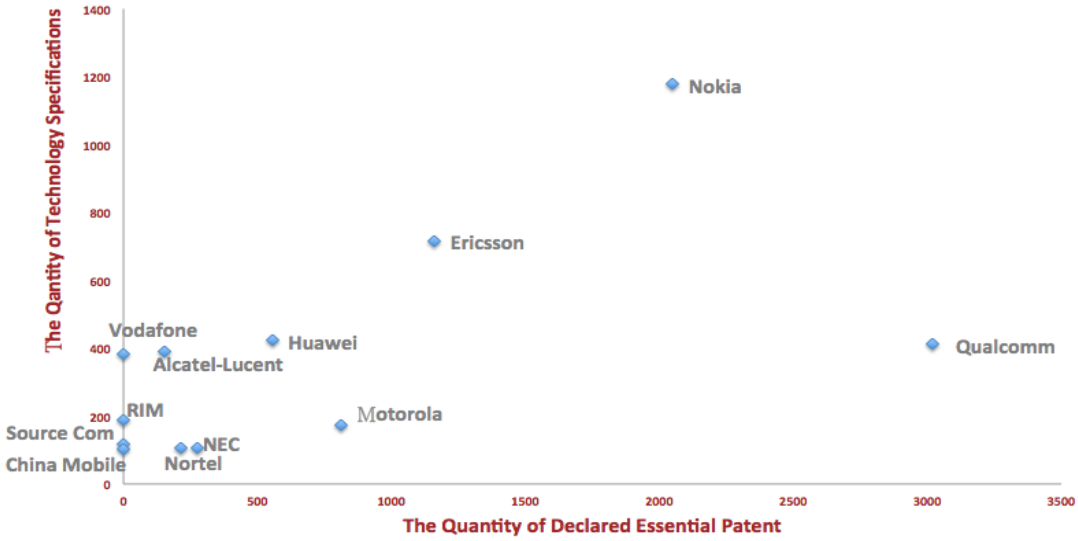
[18] The percentages of declared essential patents published at the U.S. and European patent offices of the worldwide declared essential patents approximated 25.05%.

[19] Nokia's "quantity of technology specifications" and "quantity of declared essential patents" were 1178 and 2051; Ericsson's were 716 and 1162; Motorola's were 175 and 813; Qualcomm's 411 and 3020; Alcatel-Lucent's were 392

shape two types of the relationship between the 2G GSM and 3G UMTS technology specifications and declared essential patents. One type is found with the traditional leading standard setters: Nokia, Ericsson, and Motorola. These standard setters created technology specifications while also declaring sufficient essential patents to prevent non-standard setters from infringing on the advantage of standard setters' proprietary knowledge. The other type is represented by Qualcomm, who did not create so many technology specifications as Nokia and Ericsson, but declared more essential patents than Nokia and Ericsson[20]. This finding confirms that it is very important for standard setters like Nokia to declare patents so that they can reduce non-standard setters' infringements on standard setters' efforts for setting technology specifications.

In the remainder, we used the "UCInet" analysis tool to examine the knowledge management of Nokia, Ericsson, Motorola and Qualcomm. In particular, we focused on the relationship between their technology specifications and declared essential patents published at the U.S. and European patent offices from 1988 to 2012.

Figure 4 Firms' 2G GSM and 3G UMTS Technology Specifications and Declared Essential Patents (1988 to 2012, published by U.S. and European patent offices)



(Source from 3GPP technology specifications: http://www.3gpp.org and ETSI declared essential patents: http://www.etsi.org/services/ipr-database, analyzed by authors)

and 153; Vodafone's were 384 and 0; Huawei's were 423 and 557; RIM's were 189 and 0; Source Com's were 119 and 0; Nortel's were 107 and 213; NEC's were 107 and 277; China Mobile's were 104 and 0, respectively.

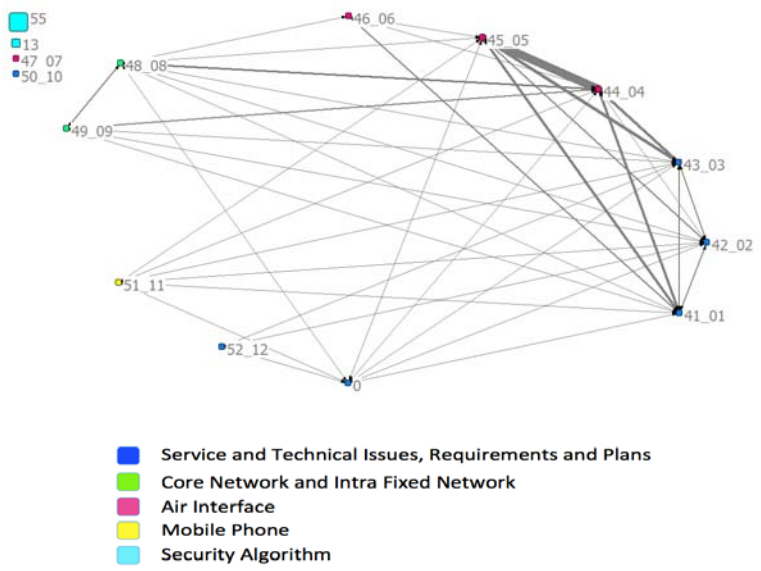
[20] This finding echoed with Goodman and Myers (2005) is that during the 3G UMTS technology standardization, Nokia and Qualcomm accused each other of falsely reporting the quantities of their essential patents, which means that they did not have to pay license fees to the opposite party as demanded.

First, Figure 5 and Figure 6 show the relationships between technology specifications connected by the worldwide declared essential patents respectively as for 2G GSM and 3G UMTS. In these Figures, the nodes and lines respectively represent the series number of technology specifications defined by 3GPP and relevant declared essential patents. The more the quantity of declared essential patents connected amongst technology specifications is, the thicker the lines are. Moreover, in order to visually highlight those technology specifications which belong to each level of telecommunication system, the nodes are colored with deep blue, green, red, yellow and light blue respectively for "Service and Technical Issues, Requirements and Plans," "Core Network and Intra Fixed Network," "Air Interface," "Mobile Phone" and "Security Algorithm" of telecommunication system.

As shown in the Figure 6, the 36 series technology specifications (i.e., "Service and Technical Issues, Requirements and Plans" level) were strongly connected with the 25 series technology specifications (i.e., "Air Interface" level) by various declared essential patents. Besides, the 36 series technology specifications also had relationships with other series technology specifications except the 30, 35 and 28 series technology specifications via declared essential patents. This means that when implementing a new telecommunication service by setting the 36 series technology specifications, standard setters actively declare essential patents with the technology specifications related to "Core Network and Intra Fixed Network," "Mobile Phone" and "Security Algorithm" as well as the "Air Interface" technology specifications.

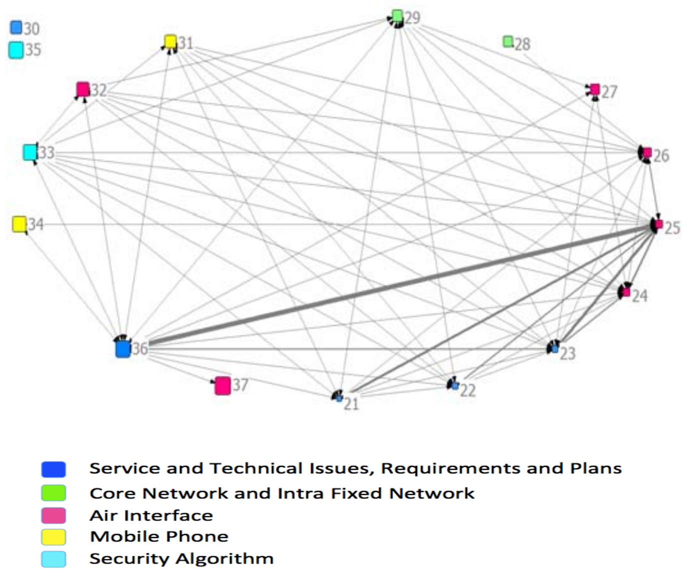
Furthermore, these Figures reveal that the 3G UMTS technology specifications are more strongly connected by various worldwide declared essential patents than the case of the 2G GSM technology specifications. By using the "Density" analysis of UCInet and controlling regions (i.e., U.S., Europe, Japan and China) where essential patents were published, we found the same situations as above-mentioned. In the case of 2G GSM, the "Density" of technology specifications connected by the declared essential patents of the worldwide, the U.S., Europe, Japan, and China was respectively 0.371, 0.371, 0.362, 0.343, and 0.286. In the case of 3G UMTS, the "Density" of these regions each was represented in 0.434, 0.426, 0.419, 0.397, and 0.382. These results indicate that standard setters would start from appropriating and sustaining their knowledge to themselves to the certain extent in the creation of the 2G GSM technology specifications with declaring patents under the FRAND license terms and continue such knowledge management to the 3G UMTS technology specifications as well.

Figure 5 Relationships between 2G GSM Technology Specifications Connected by Worldwide Declared Essential Patents.



(Source from 3GPP technology specifications: http://www.3gpp.org and ETSI declared essential patents: http://www.etsi.org/services/ipr-database, analyzed by authors)

Figure 6 Relationships between 3G UMTS Technology Specifications Connected by Worldwide Declared Essential Patents.



(Source from 3GPP technology specifications: http://www.3gpp.org and ETSI declared essential patents: http://www.etsi.org/services/ipr-database, analyzed by authors)

Next, in order to understand how standard setters appropriated their knowledge to themselves in setting technology specifications with declaring patents under the FRAND license terms from 1988 to 2012, we further grouped the "technology specifications" and "declared essential patents (only belonged to the U.S. and European patent offices)" of Nokia, Ericsson, Motorola and Qualcomm in accordance with the 5 levels of telecommunication system. Here, Nokia, Ericsson, Motorola and Qualcomm are presumed to be representative standard setters because the total ratio of the declared essential patents of Nokia, Ericsson, Motorola and Qualcomm approximated 43.79%. Moreover, we adopted Krackhardt and Stern (1988)'s "External-Internal Index" to examine whether Nokia, Ericsson, Motorola and Qualcomm appropriated their knowledge to themselves by declaring essential patents to technology specifications within a certain level or across multiple levels of telecommunication system from 1988 to 2012. The "External-Internal Index" was used to measure the extent of interdependences amongst various elements of a system. If the technology interdependences are divided equally, the External-Internal index will equal to zero. As the "External-Internal Index" approaches -1.0, those particular elements have stronger internal interdependences but weaker relationships with other levels of telecommunication architecture: technology specifications connected by declared essential patents only within a certain individual level (i.e., each level of telecommunication system are mutually independent without being connected by any declared essential patents). Conversely, as the "External-Internal Index" index approaches +1.0 at each level, those particular elements at a certain level of telecommunication architecture have weaker internal interdependences but stronger relationships with the other levels: multiple levels of telecommunication system are interdependently connected by declared essential patents.

In order to easily examine the differences between leading standard setters, we observed the cases of Nokia, Ericsson, Motorola and Qualcomm for 5 years cumulated periods from 1988 to 2012. Figure 7 shows that except Nokia's "External-Internal Index" in "Service and Technical Issues, Requirements and Plans" and "Air interface" with negative degrees during 1990-1999, Nokia, Ericsson, Motorola and Qualcomm all had positive degrees in all the 5 levels of telecommunication system. This result implies that standard setters declare their patents not only related to technology specifications belonging to certain individual levels but also related to various technology specifications across different levels of telecommunication system.

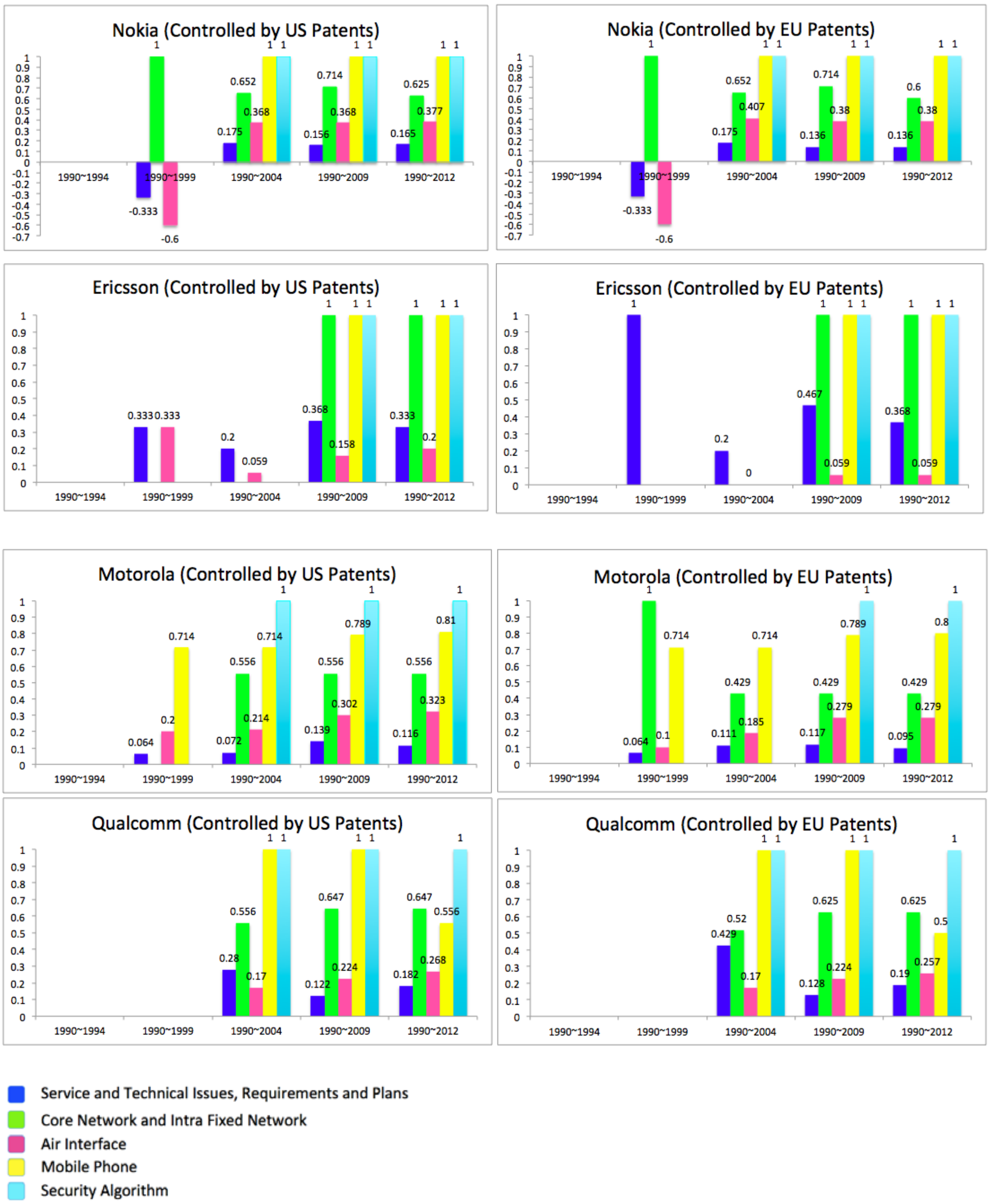
In particular, both the extent of interdependencies between the technology specifications related to "Mobile Phone" and the technology specifications related to other levels, and the extent of interdependencies between the technology specifications related to "Security Algorithm" and the technology specifications related to other levels were highest in the cases of Nokia, Ericsson, Motorola and Qualcomm. Conversely, the extent of interdependencies between the technology specifications related to “Air Interface” and the technology specifications related to other levels were lowest in the cases of Nokia, Ericsson, Motorola and Qualcomm. Interestingly, except Ericsson, the cases of Nokia, Motorola and Qualcomm all showed that the extent of the interdependencies of the technology specifications related to a particular level with the technology specifications related to other level were ranked from the highest of “Security Algorithm”, “Mobile Phone”, “Core Network and Intra Fixed Network”, “Air Interface” to the lowest of “Service and Technical Issues, Requirements and Plans”.

These results indicate that the telecommunication system is not a completed modular system. Rather, various technology specifications of multiple levels of telecommunication system need to interact with each other when standard setters are in pursuit of sustaining innovations of their infrastructures and mobile phones. In that case, declaring essential patents may help standard setters secure property rights to appropriate their knowledge to themselves regarding interdependent technology information amongst the 5 levels of telecommunication system.

This explanation can also extend our understanding on the technology development of telecommunication system. New entrant are allowed to exploit the technology specifications created by standard setters. However, new entrants should face more difficulties to develop their products than leading standard setters. In contrast, standard setters engaged in standardization would be at an advantage of learning to cope with multiple levels of technology specifications connected by their declared essential patents.

Figure 7 External-Internal Index of Standard Setters' 2G GSM and 3G UMTS Technology Specifications and Declared Essential Patents Published by U.S. and European Patent Offices

2G GSM 3G UMTS



(Source from 3GPP technology specifications: http://www.3gpp.org and ETSI declared essential patents: http://www.etsi.org/services/ipr-database, analyzed by authors)

6. Discussion

Existing studies have emphasized firms' standardization strategies presumed to support firms' business competitiveness and/or firms' related patent strategies (by essential patents) to "appropriate" their technologies in standardization. Such studies have primarily examined the criticality of setting technology specifications and/or the quantities of standard setters' essential patents. In the meantime, our study attempts to examine standard setters' knowledge management by exploring their "intra-firm" networks of technology specifications and declared essential patents in consideration of technology diffusion through standardization.

Setting standardized technology specifications, which increases the adaptability and compatibility of components/subsystems with the whole system, can help standard setters' product systems being quickly and widely accepted by the market (Carlsson and Stankiewicz, 1999; Farrell and Simcoe, 2007). Such technology specifications will work better on standard setters' proprietary systems, and better fit standard setters' business models in pursuit of their private benefits of product development (Funk, 2002; 2009).

Our results shows that leading standard setters, Nokia, Ericsson, Motorola, were likely to create a wide range of the 2G GSM and 3G UMTS technology specifications related to a whole telecommunication system. Some new technology specifications were derived from their existing technology specifications. These results imply that leading standard setters have been reinforcing technology specifications closely related to their existing proprietary knowledge so that every parts of their telecommunication system products can be well-accepted by various operators and competitors.

At the same time, it is also important for standard setters to declare their patents as being essential patents on the technology specifications under FRAND license terms in order to avoid non-standard setters' free-riding infringement on their proprietary knowledge. For instance, as shown in our results, the declared essential patents of Nokia, Ericsson and Motorola were concentrated on specific fields of technology specifications critical for mobile phone development: "Air Interface" and "Core Network and Intra Fixed Network." Therefore, new entrants' mobile phone development have been required to pay extra license fees to Nokia, Ericsson and Motorola for using their technologies essential to product development in the industry.

However, declaring essential patents does not sufficiently explicate leading standard setters' continuous and distinct advantages in product development over new entrants. Our semi-structure interviews support that the telecommunication products of Nokia, Ericsson and Motorola could be regarded as the golden samples or reference devices for other firms' mobile phone development[21]. The

[21] Only firms, like Nokia, who created a wide range of technology specifications could clearly understand the real logics and descriptions written in those technology specifications for solving technical problems related to "Air Interface" (interview with Frank Chen, a technology marketing manager of Nokia-Siemens, on 23, July 2012;

fact corroborates that while reinforcing existing knowledge on a wide range of technology specifications, standard setters can continuously lead product development in the industry and thereby establish advantages over their competitors even under the surge of standardization. The accumulated networks of knowledge regarding to the interdependencies between technology specifications and declared essential patents, shown in this study, can further reveal why Nokia, Ericsson and Motorola could continuously release their telecommunication products prior to other competitors and secured their market shares.

The development of complex product systems, like telecommunication system, require firms to integrate and combine externally different domain knowledge (Brusoni and Precipe, 2001; Brusoni, Precipe and Pavitt, 2001; Hobday, 1995; 1998; 2001). The results of this study show standard setters' capabilities (i.e., knowledge) to be found in the management of different domains of knowledge inside themselves particularly for developing complex systems. Drawing on the results, this study can suggest that particularly for the development of complex product systems in standardization, it is important for standard setters to conduct knowledge management in terms of dealing with the interdependencies between technology specifications and declared essential patents.

The results of the networks of technologies within leading standard setters provide a witnessing fact that even under the surge of standardization, standard setters' competitiveness particularly in the development of complex product system rests on architectural knowledge. Dealing with the interdependencies between technology specifications and declared essential patents will require standard setters to have architectural knowledge rather than the simple aggregation of element knowledge (Henderson and Clark, 1990; Henderson and Cockburn, 1994).

Leading standard setters examined in this study did not separately pursue various fields of technology specifications and declared essential patents. Rather, these standard setters were proficient in controlling the interdependencies, the networks, between a variety of fields of technology specifications and declared essential patents. Furthermore, these firms developed such networks centering on a few critical technology fields such as "Air Interface" and "Core Network and Intra Fixed Network." These findings indicate that standard setters need to maintain their firm-specific architectural knowledge to align their technology developments with continuous improvements on every part of product systems in standardization. Otherwise, standard setters cannot properly allocate

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interviewed with Yamamoto, Masahiko, president of Matsushita Communication United Kingdom (1997-2001), 29, November 2007). Moreover, the "Air Interface" between infrastructures and mobile phones is also relative to telecommunication regulation, local topography and temperature, and the parameters of telecommunication equipment: only firms that are continuously creating relative technology specifications, like Nokia, could hold sufficient technology knowledge to adjust parameters for acquiring the best signal coverage, low power consumption, and high stability of cell-switching (interviewed with Ilkka Rahnasto, vice president, deputy chief legal officer of Nokia, 14, September 2014).

their technologies to various technology specifications by declaring essential patents. This study contributes to describing and explicating the statuses and transitions of such knowledge.

The contribution of this study is also found in proposing the approach and perspective to reveal the status and transition of such elusive knowledge, capabilities, by structured quantitative data. Previous studies suggest that firms can learn, align and accumulate knowledge of product development through firms' attendance in standardization. Based on such antecedents, the study shows with structured quantitative data how it is vital for standard setters to meticulously deal with knowledge management by creating technology specifications harmonized with declaring essential patents. The approach and perspective of this study will help the future development of empirical studies on standard setters' knowledge management.

7. Conclusion

By examining the networks of technology specifications and declared essential patents of standard setters, this study attempts to envisage how standard setters manage their knowledge to sustain their competitive advantages. First, we reviewed past studies on standard setters' strategies, and thereby proposed our research question: why standard setters can sustain their competitive advantage in spite of the diffusion of their knowledge for the long period of standardization. Second, by focusing on technology specifications and declared essential patents as critical knowledge to be managed, we proposed our framework, research focus, and methodology to capture the knowledge management of standard setters. Third, we examined standard setters' knowledge management by analyzing the networks of technology specifications and declared essential patents of the focused standard setters. Following the results, strategic implications were discussed in relation to standard setters' knowledge management to sustain competitive advantage in product development. This study also provided a practical implication that firms engaged in standardization need to conduct their knowledge management effectively and strategically by integrating knowledge in terms of the architectural aspect of the product system concerned. Firms are expected to manage their knowledge across their business, standardization and patent divisions in order to effectively manage technology specifications and declared essential patents.

The limitations of this study are roughly classified into three issues. First, while envisaging the foundation of competitive knowledge management in standardization, this study did not sufficiently examine the differences of the networks of technology specifications and declared essential patents between standard setters even though such differences should result in different performances of product developments between standard setters.

Second, this study lacks the examination of the decline of leading standard setters in the industry. Leading standard setters with well-developed architectural knowledge had maintained their advantages over new entrants. Nevertheless, these firms all lost their competitive advantages. Knowledge spillovers collateral with knowledge codification by the further evolution of the standardization and the spread of knowledge for implementation across firms would largely explain the decline of standard setters.

Third, relevant to the second issue, this study did not explicate non-standard setters' innovations exerted from standard setters' technology specifications or declared essential patents, which may weaken standard setters' effects on their knowledge management. For example, we found that Qualcomm was the one who declared many essential patents and thereby insisted that its patents were essential to existing technology specifications. Also other semiconductor manufacturers (e.g., TI: Texas Instruments, Freescale, Infineon, Mediatek and so on) could acknowledge the technological context of declared essential patents related to certain technology specifications, and thus improve the technologies of declared essential patents. Such manufacturers would apply to patent offices of many countries for new patents of such improved technologies[22].

Future studies will be required to explore how non-standard setters' innovations can occur through knowledge spillovers and influence incumbent standard setters' knowledge management. Such attempts will also help to elucidate how standard setters' distinctive architectural knowledge can be undermined. Lastly, standardizations in other industries (e.g., automobile, industrial machinery, other ITC industries) also should be taken into account for drawing comprehensive implications of standard setters' knowledge management in standardization.

[22] It is widely known that the Asian new entrants adopt chipsets of those semiconductor vendors to quickly develop their mobile phones (Yasumoto and Shiu, 2007). In fact, these Asian new entrants have threatened the standard setters' market shares (i.e., Nokia, Ericsson, Motorola, and so on).

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*The study is financially supported by Scientific Research (B), Grants-in-Aid for Scientific Research (KAKENHI) of MEXT in FY 2014.