Investigating Knowledge Spillovers under Standardization: The Examination of the Patent-Citation Networks in the Mobile Telecommunication Industry

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The article attempts to elucidate why incumbent standard setters lose their grounds through the knowledge spillovers under standardization. Incumbent standard setters are presumed to control innovations and interfirm divisions of labor by managing the architectural knowledge of the whole product system concerned. We conduct the analysis of patent forward citations on essential patents (SEP: Standard Essential Patent) and proprietary patents in the mobile telecommunication industry. The result shows that by the citations of essential patents from incumbent standard setters, semiconductor suppliers build their proprietary knowledge. The result also reveals that a major semiconductor supplier accelerates such spillovers of architectural knowledge.

INTRODUCTION

This research attempts to elucidate the spillovers of architectural knowledge from incumbent leading firms in order to examine the process of technology leadership[3] transfers from incumbent leading firms to core component suppliers. In traditional discussions on interfirm divisions of labor, system manufacturer capabilities are presumed to exist in the form of "knowledge" (Nonaka and Takeuchi, 1995). System manufacturers, by maintaining architectural knowledge that stipulates relationships between elements of systems, coordinate the division of labor between suppliers (Brusoni and Prencipe, 2001; Brusoni, Prencipe, and Pavitt, 2001; Takeishi, 2001; Takeishi, 2002), and promote the innovations of systems (Henderson and Clark, 1990; Henderson and Cockburn, 1994).

As such, maintaining architectural knowledge allows system manufacturers to coordinate the divisions of labor with suppliers and lead out on innovations, which then secures technological leadership and builds advantage. However, as basic system architecture is made public, as is the case of Information Communication Technology (ICT) products such as PC and DVD, "core component suppliers (e.g., Intel)," rather than system manufacturers, increase the control over interfirm divisions of labor (Gawer and Cusumano, 2002; Katz and Shapiro, 1985; Tatsumoto, Ogawa, and Fujimoto, 2009; West, 2007). In a growing number of industries, technology leadership is shifting from system manufacturers to core component suppliers, as these core component suppliers acquire architectural knowledge.

When technology leadership shifts from system manufacturers to core component suppliers, existing system manufacturers are hit by "technological hazards" that threaten their survival. Suppliers' technologies influence the future technologies and mass production opportunities of system manufacturers (de Figueiredo and Teece, 1996, p. 545). In effect, many researches have focused on "open platforms" (Boudreau, 2010; Boudreau and Hagiu, 2009; Eisenmann, Parker, and Van Alstyne, 2008; Garud and Kumaraswamy, 1993; Merges, 2008; Parker and Van Alstyne, 2008; West, 2003) and "platform leadership" (Gawer and Cusumano, 2002), examining strategies and business models of core component suppliers. However, the transfer of technology leadership from system manufacturers to core component suppliers is not well understood.

In ICT-related industries, the capturing of technology leadership in product architectures by core component suppliers is largely influenced by "technology standardization" (Gawer and Cusumano, 2002; Shapiro and Varian, 1998; West, 2007). Standardization not only helps firms coordinate knowledge dispersed across firms but also encourages knowledge transfers between firms (Steinmuller, 2003). Interfirm networks shaped along with such interfirm knowledge transfers encouraged by standardization enable the use of external knowledge by various firms, including new entrants. The formation of these networks means that core component suppliers that have acquired capabilities control innovation as interfirm network hubs, and can secure the inherent advantages (property rights). This type of process is presumed to be promoted by technology standardization[4].

Why and how do core component suppliers secure technology leadership amidst increasing standardization? How do core component suppliers impact network structures? How should firms (particularly incumbent system manufacturers) strategically respond to these trends? Examining these topics is critical to identify the process of technology leadership shifts due to knowledge transfer.

This study considers how the accumulation of knowledge to core component suppliers through standards and patents, as well as the resulting intentional knowledge spillovers[5], occurs. More specifically, this paper reviews technology leadership derived from architectural knowledge, and discusses the possibility of securing (and losing) technology leadership due to increasing standardization. Moreover, the paper presents a framework and predictions on technology leadership shifts due to knowledge spillovers amidst increasing standardization, and in addition identifies the flow of information between firms by analyzing patents related to technology specifications related to architecture knowledge. Based on the results of that analysis, the paper examines the process of the shift in technology leadership from system manufacturers to core component suppliers, and presents the implications of these findings.

LITERATURAL REVIEW

Researches to date have assumed an architecture wherein system manufacturers included core component suppliers, with development being done through system manufacturers coordinating the division of labor between suppliers. Core components of a system correspond to a system's core concepts, and are higher-order technologies. The core component has properties that determine complementary components, which are lower-order technology (Clark, 1985). As system manufacturers internalize core components with these properties, they maintain leadership in overall system technologies by having knowledge related to system architectures.

On the other hand, standardization brings with its basic system architectures that are open. Standardization promotes compatibility and interoperability between firms, thereby requiring an open approach to technology, including basic system architectures. Accordingly, even in firms that have promoted standardization, internally manufacturing core components does not strictly mean that these firms can maintain technology leadership. Rather, in these circumstances, holding onto rights to knowledge of an overall architecture for systems that are open requires the control of interfirm division of labor and the new participation of competitors or suppliers (David and Greenstein, 1990; Katz and Shapiro, 1986; Merges, 2008; Parker and Van Alstyne, 2008; West, 2003). In other words, it is critical that a company keeps control of various suppliers' access to company's system architecture, even while opening up firm's system architecture (Boudreau, 2010; Boudreau and Hagiu, 2009; Carlsson and

Stankiewicz, 1999; Eisenmann, Parker and Van Alstyne, 2008; Gawer and Cusumano, 2002; Kende, 1998; von Burg, 2001; West, 2003; 2007).

It is possible to maintain technology leadership even while contributing to standardization to open technologies. With progress in standardization, firms confirm the technology development, and redefine system architectures based on their own technologies. By reflecting their internal technologies into standards, they can bring products using those technologies to market faster than other firms (Funk, 2002; 2009; Garud and Kumaraswamy, 1993; Mansfield, 1985; West, 2007). In addition, firms that contribute to standardization secure rights to related technologies (particularly intellectual property rights) under certain conditions (Bekkers, 2001; Bekkers, Duysters, and Verspagen, 2002, Bekkers, Verspagen, and Smits, 2002; Bekkers and West, 2009). In doing so, system manufacturers promoting standardization strike the difficult balance between open knowledge and knowledge that should be leveraged as proprietary technology (Blind and Thumm, 2004; West, 2003), thereby maintaining technology leadership.

For example, researches on the mobile telecommunications industry (Funk, 2002) and workstation industry (Garud and Kumaraswamy, 1993) has supposed that firms build competitive advantage by (1) controlling the interfirm division of labor, and (2) being the first to productize innovations (implementations) by the quickest access to specifications based on their technology developments and their knowledge accumulated through leaning by doing. System manufacturers that promote standardization can also strategically design for compatibility and interoperability with components developed by suppliers, or incorporate components into products under their design strategy (Boudreau and Hagiu, 2009; Farrell and Saloner, 1992; Katz and Shapiro, 1985; Merges, 2008; Parker and Van Alstyne, 2008). In addition, by having knowledge of system architectures, system manufacturers can even reintegrate with supplier components, or other components, using proprietary methods (Davis and Murphy, 2000; Eisenmann, Parker, and Van Alstyne, 2008). In this way, system manufacturers can maintain and control architectural knowledge (with stronger technology leadership), even with greater openness in basic architectures brought about by standardization.

Knowledge of system architectures that span multiple technologies cannot be easily replicated, and leadership in those technologies should be maintainable. In other words, simply opening up an architecture enables the continued control of technologies and market entry of external suppliers. However, in many industries technology leadership is shifting to core component suppliers away from incumbent leading system manufacturers. This situation contradicts the assertion of many studies that say system manufacturers gain competitiveness through standardization (e.g. Bekkers, 2001; Bekkers, Duysters, and Verspagen, 2002; Bekkers, Verspagen, and Smits, 2002; Bekkers and West, 2009; Funk, 2002; 2009). Reflecting the issue above, we explore how core component suppliers are able to acquire the architectural knowledge same as system manufacturers. Exploring the process will also help us understand how critical knowledge can be exploited by new entrants under standardization.

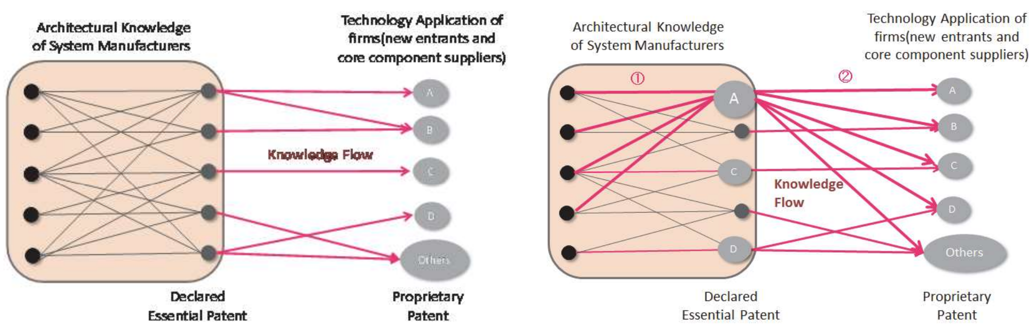
ANALYSIS FRAMEWORK

System manufacturers that promote standardization open up basic specifications of systems through applying their proposals of technology specifications[6]. Once made open as such, the technology specifications will almost certainly be used by free riders such as core component suppliers and new entrants (Kristiansen and Thumm, 1997). In actuality, the European Commission (2014, p.28) has noted, "information related to standardization is critical to product innovation in many firms, and at the same time creates externality and spillover issues." Against these circumstances, system manufacturers attempt to prevent free riders and protect rights by declaring a portion of their proprietary patents for related technologies as essential patents for technology specifications[7].

However, while firms can hold technologies as essential patents (or proprietary patents), it is difficult to maintain exclusivity (e.g. Blind and Thumm, 2004 ; David and Greenstein, 1990). Even with patents used to protect technologies as legal rights, open access to technical information increases the likelihood of knowledge leaks, and even where such knowledge is protected by patents, it can be cited in the development of technologies and products by other firms, increasing the likelihood of the technology being broadly used. Researches to date have also noted the flow of knowledge from incumbent system manufacturers to new entrants though the citation of patents related to standards (He, Lim, and Wong, 2006; Leiponen, 2008; Kang and Motohashi, 2015). This type of knowledge spillovers may lead to overturning the advantages held by incumbent leading system manufacturers.

As can be seen above, even when essential patents and various technology specifications are made open, a complex relationship between technology specifications based on the declaration of essential patents means the knowledge of system architectures is also complex[8]. In such a case, it is difficult for core component suppliers to absorb architectural knowledge, since architectural knowledge that defines relationships between multiple technologies or elements and enables the implementation of technology is implicitly held, and often concealed as knowhow. As in the case of the left side of Figure 1 below, when leading system manufacturers that have promoted standardization secure essential patents across multiple technology specifications and have a complex knowledge network, their architectural knowledge is predicted to be unlikely to spill over (Shiu and Yasumoto, 2015). This type of architectural knowledge cannot be easily obtained by referencing or citing technology specifications or patents. If that is so, system manufacturers should be able to continue to maintain technology leadership, even if technology specifications and essential patents are made open.

FIGURE 1
ANALYTICAL FRAMEWORK



Source : Illustrated by authors.

So how do spillovers of system architectural knowledge occur? As was stated above, core component suppliers can use technological information gleaned from technology specifications and essential patents in their own product and technology development. Leveraging architectural technologies in systems can be done via two routes (the right side of Figure 1). First, (1) firms can cite (or reference) technology specifications noted in standardized specifications of system manufacturers, and declare essential patents. In the second, (2) it is possible for them to cite the essential patents of system manufacturers, and apply for proprietary patents.

With an increasing amount of activity (1), knowledge becomes more open as core component suppliers declare essential patents. This results in more of activity (2), with core component suppliers further citing this knowledge and applying for more of proprietary patents. In particular, as specific firms aggressively push activity (1), knowledge becomes concentrated in those firms, and this knowledge is made open in the form of essential patents. New entrants and core component suppliers can lower their knowledge search costs by using these open essential patents, and thus learn to absorbe knowledge from certain firms. The flows of knowledge (1) and (2) due to this type of core component supplier behavior is predicted to be connected to spillovers of architectural knowledge from system manufacturers.

Based on the above points, this study focuses on the relationship between technology specifications and essential patents, and explains how incumbent leading system manufacturers hold onto product architecture knowledge based on standardization. Moreover, the study examines how essential patents relate to technology specifications, and what kind of proprietary patents are obtained. By focusing on these sorts of knowledge acquisition routes in examining spillovers of architectural knowledge by system manufacturers across multiple technology specifications, it is possible to examine the weakening of technology leadership among incumbent leading system manufacturers.

SAMPLES AND DATA

Samples

Mobile telecommunications systems were selected as subjects of analysis for this study[9]. The reason for selecting Nokia, Ericsson, and Motorola as system manufacturers is their technology leadership in the complex 2G GSM and 3G UMTS telecommunications systems within the telecommunications industry[10]. Another reason was that Nokia, Ericsson, and Motorola had a high percentage of the total number of essential patents and technology specification proposals from April 4, 1990 to October 2, 2012 (Shiu and Yasumoto, 2015). These system manufacturers are thought to have controlled the market entry of new firms and technological progress through these technology specifications and essential patents. Thus, Nokia, Ericsson, and Motorola had architectural knowledge related to telecommunications systems that allowed them to keep a grip on technology leadership, and are therefore well suited for the issues examined in this study.

On the other hand, Qualcomm, Freescale, Infineon, Texas Instruments, Mediatek, and Spreadtrum, all semiconductor suppliers, were selected as core component suppliers. This is because these suppliers also control the market entry of new firms and technological progress, and have a lock on technology leadership[11]. These six core component suppliers are thought to have eroded the relative technology leadership of Nokia, Ericsson, and Motorola, and are thus well suited for this study. In order to compare and contrast in this paper, in addition to the aforementioned core component suppliers, we also examine the knowledge flows from Nokia, Ericsson, and Motorola to major mobile handset new entrants Samsung, LG, Apple, and Huawei.

Data

By focusing on architectural knowledge of system manufacturers of mobile telecommunications systems, this study examines spillover of knowledge and shifts in technology leadership. Technology specifications disclose basic specifications of architecture, while essential patents include technical information related to management and implementation. Accordingly, by observing how new entrants and core component suppliers leverage technology specifications and essential patents, it should be possible to clarify the flow of information between firms in the mobile telecommunications industry[12].

For this study, a total of 6,243 2G GSM and 3G UMTS technology specifications[13] between April 1988 and December 2009 were acquired from the 3GPP website. In addition, a total of 16,493 2G GSM and 3G UMTS essential patents (those US and European patents declared by firms to ETSI) from between April 1990 and October 2012 were obtained from the ETSI website[14]. Moreover, the 16,493 essential patents were mapped to the 6,243 technology specifications based on information from the technology specifications noted in the essential patents in order to identify knowledge flow (1). The positions of the essential patents within a mobile telecommunications system architecture were then categorized.

Five software engineers and seven hardware engineers from a Taiwanese mobile phone ODM (original design manufacturer) cooperated in this effort, categorizing the technology specifications within the telecommunications systems architecture as shown in Table 1 according to the categories of 1) telecommunications services, technical issues, and plans; 2) core network and intra fixed network; 3) air interface; 4) mobile phone; and 5) security and encryption algorithms[15]. Secondary data such as technology documents and reports, or magazine and newspaper articles were also referenced[16], to gain a more accurate understanding of information in technology specifications within the standardization activities of the telecommunications industry.

TABLE 1
CLASSIFICATION OF TECHNOLOGY SPECIFICATIONS

Telecommunication System	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：Shiu and Yasumoto (2015)

Patent forward citation data was compiled on essential patents of proprietary patents in order to examine knowledge flow (2). Patent forward citations are a standard tool for examining knowledge flow between firms (Jaffe and Trajtenberg, 2002; Jaffe, Trajtenberg, and Henderson, 1993)[17]. In this study, all proprietary patents of six core component suppliers[18] and four new entrants[19] were extracted from the EPO (European Patent Office) Espacenet patent database, with no limits on time period. The search resulted in 215,649 patents from the US, and 75,464 from Europe[20]. Moreover, based on the application date for the proprietary patents of these ten firms, as well as the declared date of the essential patents declared by the ETSI, patent forward citations for US essential patents numbered 21,010, while there were 643 for Europe, making a total of 21,653[21]. Based on this fact, we can understand the commonalities and differences of "the knowledge flow from Nokia, Ericsson, and Motorola to the six core component suppliers" and "the knowledge flow from Nokia, Ericsson, and Motorola to the four new entrants."

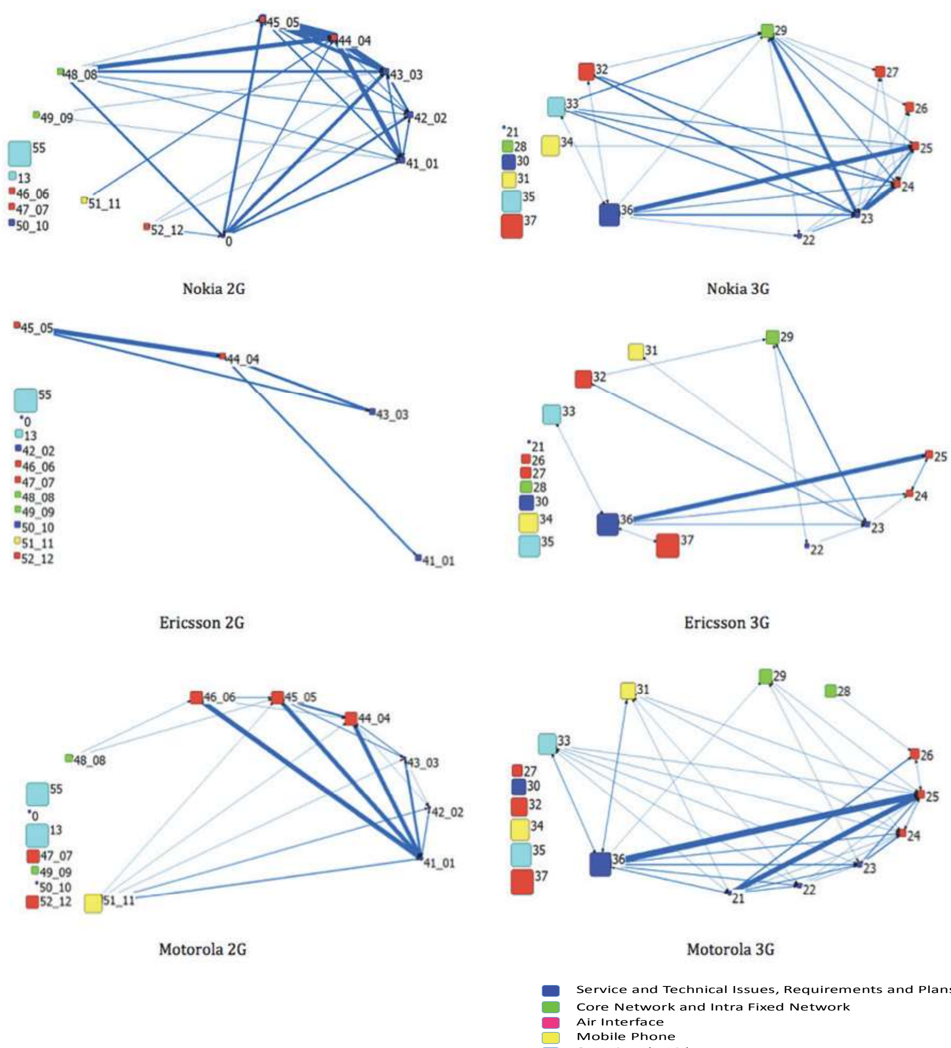
CASE STUDIES

Architectural knowledge of mobile telecommunications systems

An explanation of corporate architectural knowledge requires an understanding of the relationship between each firms' technology specifications and essential patents. In addition to the technology specification data, this study also uses declaration documents for 64,228 essential patents for the period of April 4, 1990 to October 2, 2012, and calculates technology specification "density" and the central value of technical specification categories (nodes) using "Density" and "Degree Centrality" from the UCInet network tool. Higher "density" of technology specifications according to the declaration of a firm's essential patents means a firm has a broader range of control of mobile telecommunications system architecture than other firms, and that that a firm's architectural knowledge is complex. On the other hand, knowing the "central value" of a technology specification tells one the type of knowledge most critical within the complex architectural knowledge of a firm.

Figure 2 shows the results of this analysis, with blue, green, purple, yellow, and azure nodes representing technology specifications related to “telecommunications services, technical issues, and plans”; “core network and intra fixed network”; “air interface”; “mobile phone”; and “security and encryption algorithms”, respectively. The blue lines between nodes represent essential patents. Because essential patents can correspond to multiple technology specifications, node size and line thickness represent the number of essential patents in relationship to a technology specification. In Figure 2, the nodes shown as being independent of Nokia, Ericsson, and Motorola on the left show that an essential patent is declared as being tied to only one specific technology specification. While there are differences between 2G GSM and 3G UMTS, one can see that the densities of technology specifications from Nokia, Ericsson, and Motorola are quite high[22]. This shows that each firm broadly declares essential patents across multiple technology specifications related to mobile telecommunications systems, and that these firms control the architectures of these systems[23].

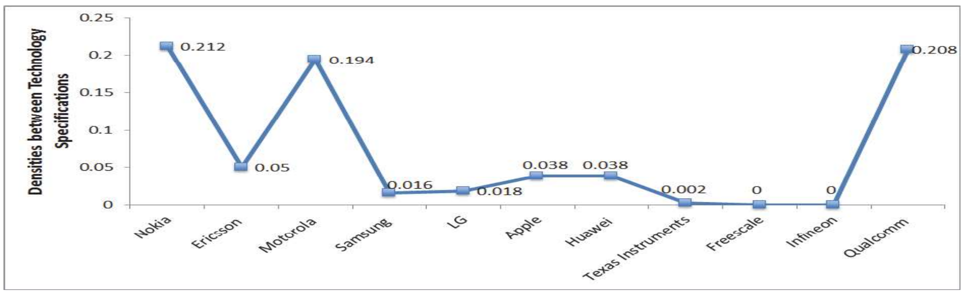
FIGURE 2
NETWORKS BETWEEN TECHNOLOGY SPECIFICATIONS OF NOKIA, ERICSSON, AND MOTOROLA



Source: Authors’ analysis by using ETSI and Espacenet data

Figure 3[24]below shows the densities of technology specifications (combined 2G GSM and 3G UMTS) from Nokia, Ericsson, and Motorola, the six core component suppliers, and the four new entrants. Core component suppliers Mediatek and Spreadtrum have not declared any essential patents, and are thus left out of this analysis. Freescale and Infineon have declared few essential patents, making the densities between their technology specifications effectively zero. The densities of Nokia, Ericsson, and Motorola are 0.212, 0.05, and 0.194 respectively, which are higher than Samsung (0.016), LG (0.018), Apple (0.038), Huawei (0.038), and Texas Instruments (0.002). However, Qualcomm's density is 0.208, and Nokia's 0.212.

FIGURE 3
DENSITIES BETWEEN TECHNOLOGY SPECIFICATIONS AT MAJOR FIRMS



Source：Authors' analysis by using ETSI and Espacenet data

Next, by using UCInet's "Degree Centrality", categories of technology specifications for which there are many essential patent declarations are identified[25]. Further, for convenience in analysis, the central value of each technology specification was summed for each of the following categories shown in Table 1: "telecommunications services, technical issues, and plans"; "core network and intra fixed network"; "air interface"; "mobile phone"; and "security and encryption algorithms". As shown in Table 2, the central values of technical specifications related to "telecommunications services, technical issues, and plans" and "air interface" are higher than those from other technology specifications. Nokia, Ericsson, and Motorola all declare essential patents related to overall mobile telecommunications, and at the same time exert strong control over interface technologies ("telecommunications services, technical issues, and plans" and "air interface") needed to connect to mobile telecommunications systems[26].

TABLE 2
DEGREE CENTRALITIES BETWEEN TECHNOLOGY SPECIFICATIONS AND ESSENTIAL PATENTS BY THE CLASSIFICATION OF TECHNOLOGY SPECIFICATIONS AND FIRMS

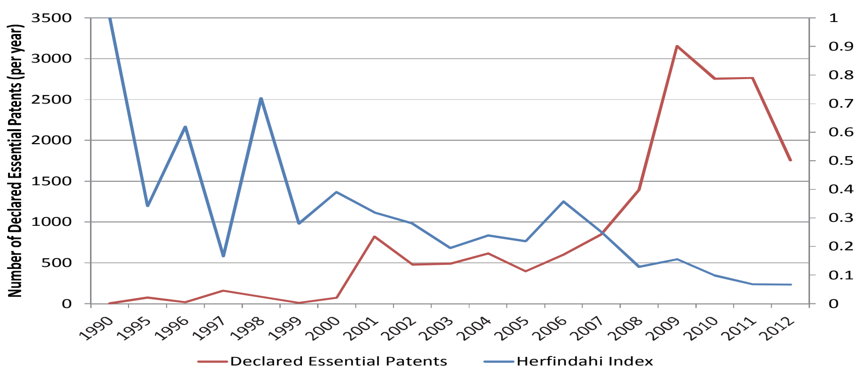
The Classification of Technology Specifications	Nokia	Ericsson	Motorola	Samsung	LG	Apple	Huawei	Qualcomm	Texas Instruments	Freescale	Infineon
Service and Technical Issues, Requirements and Plans	14751	4518	46936	3585	7123	6282	1333	84319	605	736	23
Core Network and Intra Fixed Network	2847	249	217	6	0	10	166	9035	0	0	0
Air Interface	16699	1879	11303	600	4422	1100	362	148769	408	0	31
Mobile Phone	80	6	506	8	0	3	0	164	0	0	0
Security Algorithm	1454	34	330	7	0	29	114	798	0	0	0
Notice 1: These values were calculated by using the data of 2G GSM and 3G UMTS technology specifications and essential patents (U.S. and European).											
Notice 2: Mediatek and Spreadtrum were excluded from this analysis due to they have not declared their essential patents.											

Source：Authors' analysis by using ETSI and Espacenet data

Trends in essential patent declarations based on technology specifications

As can be seen in Figure 4, the concentration (Herfindahl Index)[27] of essential patent declarations by specific corporations rose from 0.22 in 2005 to 0.36 in 2006, though it has declined every year since. In particular, after 2005, increasing standardization of mobile telecommunications systems is predicted to reduce the percentage of essential patents declared by Nokia, Ericsson, or Motorola of the total essential patents[28].

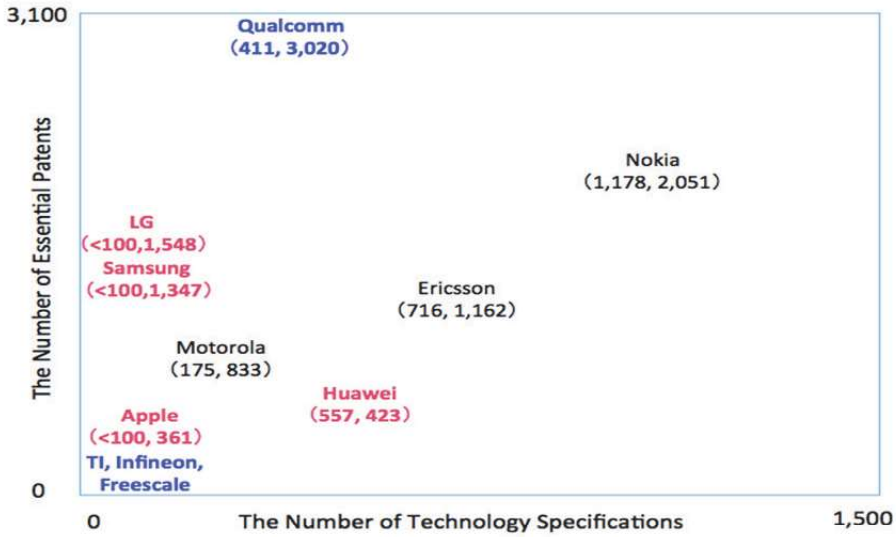
FIGURE 4
TREND OF THE DECLARATION OF FIRMS' ESSENTIAL PATENS AND ITS HERFINDAL INDEX



Source：Authors' analysis by using ETSI data

As can be seen in Figure 5, Nokia, Ericsson, and Motorola developed 1,178, 716, and 175 technology specifications respectively, while Qualcomm had only 423. In addition, the ratio of technology specifications to essential patent declarations was 1.74 for Nokia, 1.62 for Ericsson, and 1.13 for Motorola, while Qualcomm's was approximately 7.35; Samsung, 13.47; LG, 15.48; Apple, 3.61; and Huawei, 0.76[29]. In particular, the technology specifications of Qualcomm were used the most, and Nokia had 1.5 times the essential patent declarations. It is not an exaggeration to state that these firms actually control mobile telecommunications system architectures[30].

FIGURE 5
NUMBER OF FIRMS' TECHNOLOGY SPECIFICATIONS AND ESSENTIAL PATENTS



Source: Authors' analysis by using ETSI and Espacenet Data

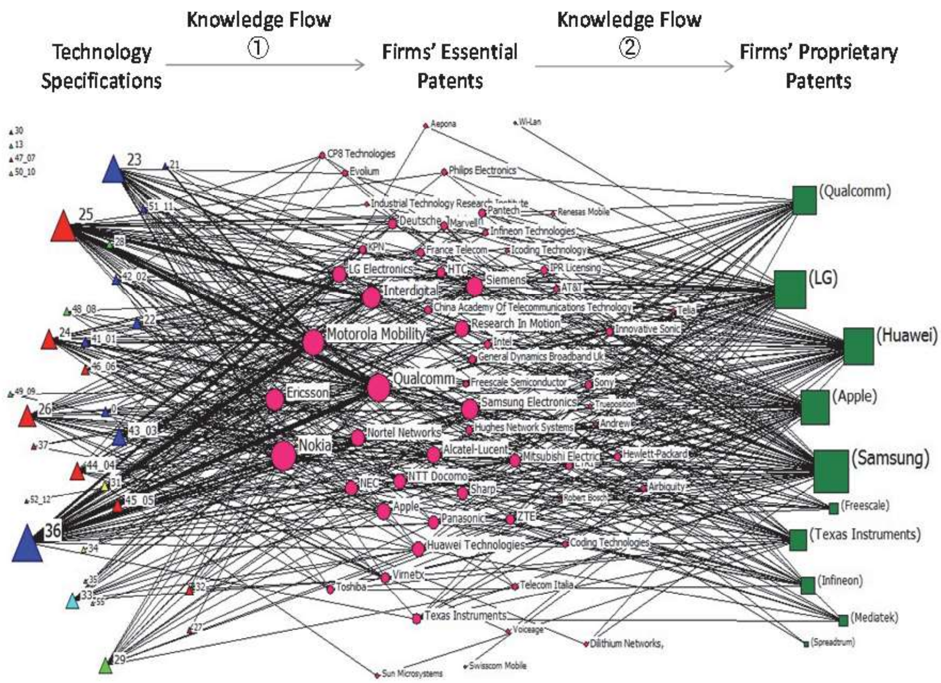
Knowledge flow between technology specifications, essential patents, and proprietary patents

In this paper we are examining the acquisition of knowledge among new entrants and core component suppliers through (1) the use of technology specifications, and (2) the use of essential patents. The data in 4.2 was used for both (1) and (2) to explain the relationships between knowledge flows in each[31]. For the relationship between technology specifications and essential patents (knowledge flow (1)), the data was limited to essential patents cited by the four new entrants and six core component suppliers. In addition, corresponding relationships were only used once to avoid double counting. For example, even though an essential patent may be cited twice, only the original corresponding relationship between an essential patent and a technology specification was counted. On the other hand, for citations of essential patents by proprietary patents (knowledge flow (2)), proprietary patents of the four new entrants and six core component suppliers, and the aforementioned essential patents were considered.

Figure 6 below shows the overall network of knowledge flow (1) from technology specifications to essential patents, and knowledge flow (2) from essential patents to proprietary patents. The ten square nodes on the right side represent the six core component suppliers and the four new entrants. In addition, the size of each square denotes the total number of essential patent citations by each firm; a larger square means more essential patent citations. The circular nodes are the 61 firms that have declared essential patents using proprietary patents in Europe and the US. The triangular nodes represent technology specifications.

The blue, green, purple, yellow, and azure colors represent technology specifications regarding "telecommunications services, technical issues, and plans"; "core network and intra fixed network"; "air interface"; "mobile phone"; and "security and encryption algorithms", respectively. In addition, a thicker line connecting nodes represents a higher number of correspondences between technology specifications and essential patents (knowledge flow (1)) or between essential patents and proprietary patents (knowledge flow (2)). For example, Qualcomm's essential patents were declared using multiple technology specifications, and there are many essential patent declarations for 25-series and 36-series technology specifications.

FIGURE 6
NETWORK OF TECHNOLOGY SPECIFICATIONS, ESSENTIAL PATENTS AND PROPRIETARY PATENTS



Source：Authors' analysis by using ETSI and Espacenet data

First, the density of each knowledge flow was calculated using UCInet's "Density". As can be seen in Table 3, the density of technology specification-essential patent networks (knowledge flow (1)) was 0.107 between 1990 and 1997, climbing to 0.169 in 2012. On the other hand, the density of essential patent-proprietary patent networks (knowledge flow (2)) was 0.308 between 1990 and 1997, climbing to 0.537 in 2012. Citations of essential patents by proprietary patents (knowledge flow (2)) grew along with the relationship between technology specifications and essential patents (knowledge flow (1)). This suggests that standardization of mobile telecommunications technologies between 1990 and 2012 caused knowledge flow (1) and promoted knowledge flow (2). As was shown in 5.1, Nokia, Ericsson, and Motorola should have control of knowledge flow (1), but they have not promoted knowledge flow (2). This has been done by Qualcomm and other firms, where there has been a connection between the two knowledge flows.

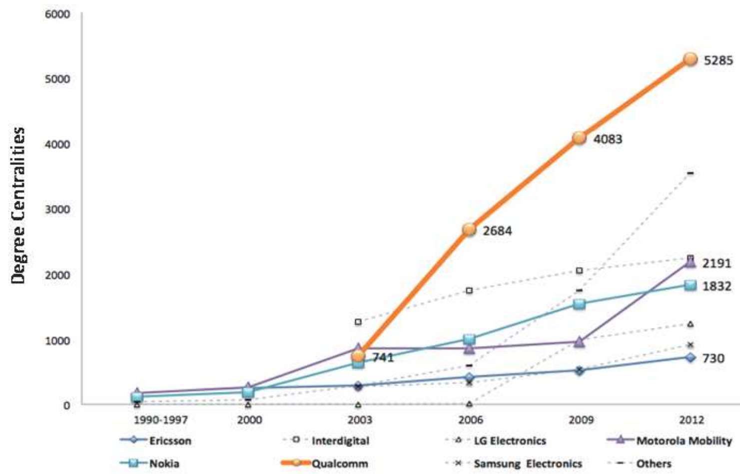
TABLE3
NETWORK DEGREE DENSITIES OF KNOWLEDGE FLOW (1) AND (2)

Network of Technology Specifications and Essential Patents（Knowledge Flow①）						
	1990-1997	1990-2000	1990-2003	1990-2006	1990-2009	1990-2012
Density	0.107	0.099	0.155	0.166	0.169	0.169
Standard Deviation	0.309	0.298	0.362	0.372	0.375	0.375
Average Degree	3.409	3.161	4.975	5.327	5.422	5.405
Network of Essential Patents and Proprietary Patents（Knowledge Flow②）						
	1990-1997	1990-2000	1990-2003	1990-2006	1990-2009	1990-2012
Density	0.308	0.345	0.43	0.439	0.506	0.537
Standard Deviation	0.462	0.475	0.495	0.496	0.5	0.499
Average Degree	3.083	3.45	4.3	4.395	5.063	5.371
Note: These values were calculated by using “Cohesion” and “Density” of UCInet.						

Source: Authors’ analysis by using ETSI and Espacenet data

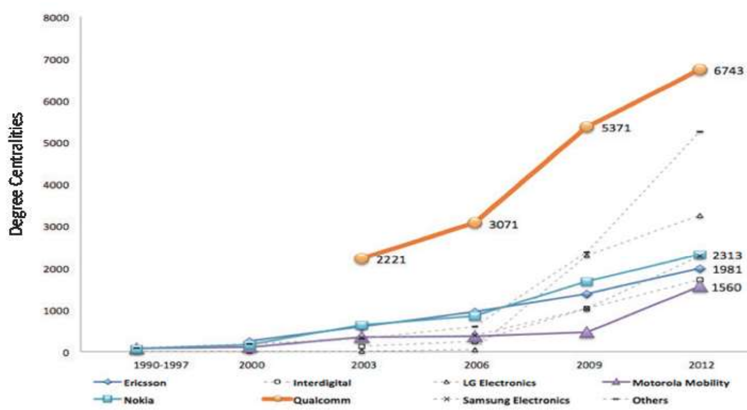
Figures 7 and 8 below show the results of this analysis. The central values for knowledge flows (1) and (2) were calculated using UCInet’s “Degree Centrality”, and the results for the top seven firms are shown in the figures. Between 1990 and 2003 Nokia, Ericsson, and Motorola have higher central values for both knowledge flows. However, from 2003 onward, knowledge flows (1) and (2) were higher for Samsung, LG, and Qualcomm, and those of Qualcomm in particular were higher than those of Nokia, Ericsson, and Motorola. In 2012, central values for both knowledge flows at Qualcomm outperformed those of Nokia, Ericsson, and Motorola, 2.9 times in the case of Nokia. In that sense, Qualcomm is expected to control mobile telecommunications architectures by declaring many more essential patents based on technology specifications than Nokia, Ericsson, and Motorola. At the same time, knowledge noted in Qualcomm’s essential patents is often used by new entrants and core component suppliers.

FIGURE 7
KNOWLEDGE FLOW ① (AGGREGATE BASIS)



Source: Authors' analysis by using ETSI and Espacenet data

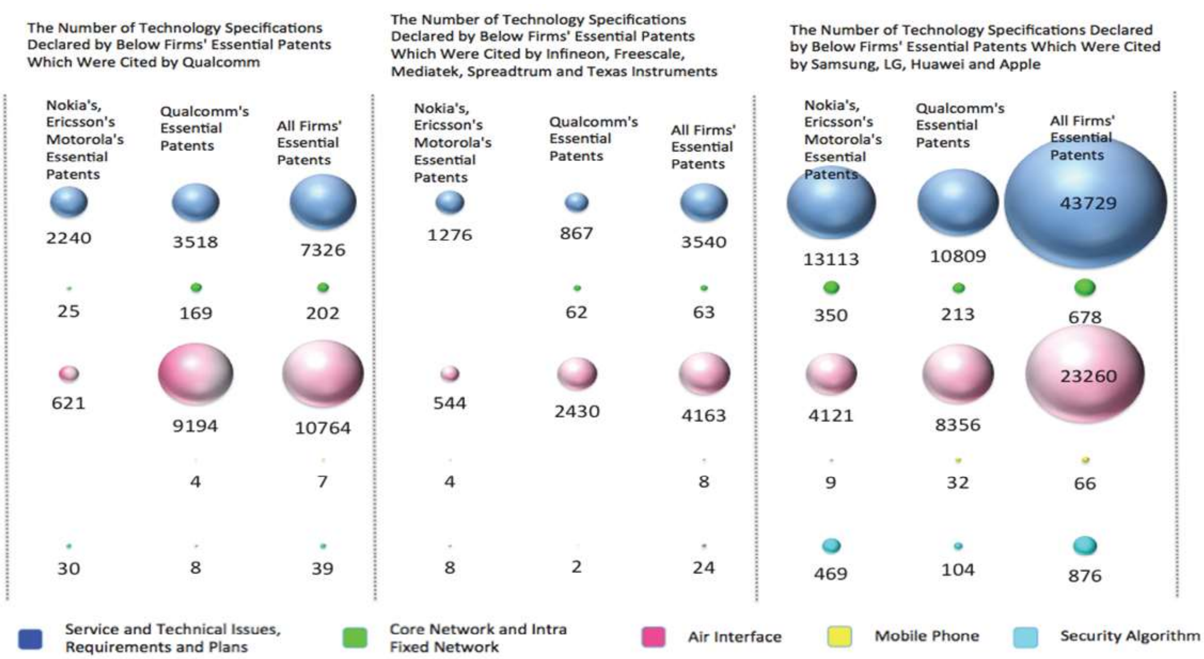
FIGURE 8
KNOWLEDGE FLOW ② (AGGREGATE BASIS)



Source: Authors' analysis by using ETSI and Espacenet data

Finally, based on the results of the above analysis, let us consider the types of knowledge spillovers caused by Qualcomm in these knowledge flows. The number of essential patent declarations by a firm cited by new entrants and core component suppliers, as well as the number of technology specifications of these essential patents by category were calculated. As is shown in Figure 9, essential patents cited by new entrants and core component suppliers primarily corresponded to "telecommunications services, technical issues, and plans" and "core network and intra fixed network"[32]. In particular, it was found that many Qualcomm essential patents cited by new entrants and core component suppliers corresponded to both "telecommunications services, technical issues, and plans" and "core network and intra fixed network".

FIGURE 9
NUMBER OF TECHNOLOGY SPECIFICATIONS DECLARED BY EACH FIRM'S ESSENTIAL PATENTS WHICH WERE CITED BY CERTAIN FIRMS



Source: Authors' analysis by using ETSI and Espacenet data

DISCUSSION

The outcomes of this study show how system manufacturers' technology leadership shifted to component suppliers in the midst of technology standardization of mobile telecommunications industry, as well as how knowledge spillovers were created through this shift. Discussions on standardization have focused on technology and exclusivity via intellectual property rights, as well as the level of openness (e.g., Bekkers and Martinelli, 2010; He, Lim, and Wong, 2006; Kang and Motohashi, 2015). In contrast, the outcomes of this study suggest that citations of essential patents (or just patents) that should protect exclusivity, and not just technology specifications of standards, promote spillovers, and that maintaining or transferring knowledge or technology leadership can be difficult depending on exclusivity and openness.

Some in the past have examined how technology citations (particularly patents) have advanced the acquisition of knowledge (or the creation of capabilities) by new entrants (e.g., Bekkers and Martinelli, 2010; He, Lim, and Wong, 2006; Kang and Motohashi, 2015). However, citing and using various technologies alone make it difficult to gain technology leadership. In the mobile telecommunications industry, the subject of this study's analysis, Nokia and other system manufacturers held architectural knowledge tied to critical technologies in a network related to technology specifications and essential patents (Shiu and Yasumoto, 2015), maintaining technology leadership of basic architectures in open systems while taking the lead on standardization.

In contrast to this situation, Qualcomm has declared a large amount of essential patents related to "telecommunications services, technical issues, and plans" and "core network and intra fixed network" technology specifications for existing mobile telecommunications systems. As a result, new entrants and core component suppliers often cite essential patents related to these two categories from Qualcomm even more than Nokia, Ericsson, and Motorola, enabling them to develop their own proprietary technologies. New entrants and core component suppliers rely on Qualcomm's essential patents, and in this sense one can say that technology leadership has shifted to Qualcomm. Qualcomm has influenced other firms regarding technological aggregation and citations even more than through the supply of its core components, and the firm acts as a knowledge hub.

With increasing standardization and greater openness in system architectures, the use and proliferation of technologies due to knowledge transfer is not proceeding uniformly, but is rather being accomplished by certain firms like Qualcomm that are acting as hubs. Knowledge flow is influenced by network structure, but it is known that the existence of players that act as bridges or hubs in connecting knowledge flows between different players or knowledge pools accelerate knowledge transfer (Reagans and McEvily, 2003; Tortoriello, Reagans, and McEvily, 2012; Venkatraman and Lee, 2004). These players consolidate disparate knowledge based on their position in a network, and by providing access to knowledge they display leadership and performance (Dhanaraj and Parkhe, 2006; Tsai, 2001; Zaheer and Bell, 2005).

As core component suppliers like Qualcomm created networks that promote knowledge flows from incumbent system manufacturers to other core component suppliers or new entrants, they have also built up network positions as hubs. The results have been networks that cause knowledge transfers to new entrants and shifts in technology leadership. These results signify dynamic changes in technology leadership in the formation of interfirm networks and the acquisition of capabilities within these firms due to knowledge transfers (Kogut, 2000). As to whether firms in these situations can maintain or secure technology leadership, this topic will require an examination of the acquisition of capabilities and strategies by a firm acting as a knowledge hub.

CONCLUSION

This research identified the process of how knowledge spillovers from incumbent leading system manufacturers like Nokia to new entrants and core component suppliers occur. Certain core component suppliers like Qualcomm declare essential patents in response to knowledge that has been standardized (via technology specifications) by incumbent leading system manufacturers. These essential patents are used by new entrants and other core component suppliers, who then apply for proprietary patents. This process shows that knowledge transfer networks are formed by Qualcomm or other core component suppliers acting as major bridges or hubs.

These results show that patents that guarantee a firm’s advantage through technological exclusivity promote knowledge spillovers just like standardization, and they encourage innovators. Rather than a firm questioning what should be standardized or patented at any point in time to protect technological exclusivity, these results suggest the need to question what should not be standardized or patented in the mid- and long-term in order to maintain architectural knowledge and leadership.

Of course, there are other issues that require further consideration. First, a detailed examination of knowledge transfers and capability creation requires not only the consideration of strategies related to standardization and intellectual property, but also the characteristics and background of the firm in question. This is because a firm’s background, such as a tendency towards standardization and patenting (Blind and Thumm, 2004) or the accumulation of intellectual property, is likely to create differences in strategies or how knowledge is transferred and capabilities created. Moreover, the structure of corporate knowledge, including the relationship between specifications and patents related to standards and knowledge related to implementations, is not well understood. Is this a reflection of how well specifications and patents related to standards are connected to knowledge related to implementations? These kinds of topics require further consideration through data analysis and interview-based surveys.

Amidst increasing standardization, system manufacturers are likely to cede technology leadership to external core component suppliers. Standardization leads to open architectural knowledge, and in these circumstances building and maintaining technology leadership require that a firm think about management of multi-faceted architectural knowledge that spans standards specifications, essential patents, proprietary patents, and other practical know-how. The contribution of this paper to these topics is in its identification of networks that promote the transfer and accumulation of knowledge, and its expansion of discussions on knowledge management in interfirm division of labor.

ENDNOTE

1. jingmingshiu@gmail.com
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3. Technology leadership in this research is from the concepts of “authority” (Foss and Foss, 2009) and “decision rights” (Foss, 2011) on problem-solving of product development required by system manufacturers.
4. Increasing standardization leads to the formation of networks with knowledge flow between firms through standards and patents. Existing researchs have emphasized access to external knowledge in existing interfirm networks, and has particularly focused on promoting the acquisition of capabilities from certain firms (Gulati, Nohria, and Zaheer, 2000; Reagans and McEvily, 2003; Tortoriello, Reagans, and McEvily, 2012). In contrast, the transfer of knowledge through standards and patents, as well as the acquisition of capabilities by new entrants does not rely on specific existing interfirm networks, and can therefore exist more universally.
5. Fallah and Ibrahim (2004) and Jaffe, Trajtenberg, and Henderson (1993) also use patent data to reveal the knowledge spillovers.
6. For example, in the mobile telecommunications industry these are such leading system manufacturers as Nokai, Ericsson, and Motorola, which have proposed open technology specifications to standards committees like 3GPP (Third Generation Partnership Project) and ETSI (European Telecommunications Standards Institute) on core networks, base stations, mobile phones, and so on.
7. Essential patents are declared as such by firms to standards organizations like ETSI, and rights to related technologies by the firms developing technologies are recognized under certain terms (commonly known as Fair, Reasonable, And Non-Discriminatory, or “FRAND”). Essential patents are viewed as necessary for the practical realization of standards, and if these rights are maintained, they are expected to impact products and technological progress, as well as license revenue and business.
8. Technology specifications show the type of knowledge elements in product systems. If a firm declares essential patents across multiple technology specifications, the knowledge elements in that a firm can be thought of as tight-knit. According to Yayavaram and Ahuja (2008), the knowledge structure of a firm can be drawn as a network. Ties within the network show relationships between various knowledge elements, and express the knowledge structure of the firm. The more tight-knit the relationships, the more mutual relevance in the knowledge, and the more complex the knowledge structure of the firm. From this perspective, these two researchers calculated to what extent patents in the semiconductor industry from 1984 to 1994 corresponded to USPTO patent categories, and analyzed the knowledge structure of firms. Fleming and Sernson (2001) used the same methodology to analyze a knowledge network using nodes (technology classes) and ties (patents). Based on these studies, this paper analyzes corporate knowledge networks with nodes (technology specifications) and ties (essential patents) to find the strategic intent of firms within standardization.
9. The architecture of mobile telecommunications systems herein is the “cellular architecture” wherein a base station manages multiple mobile telephones, and a core network covers multiple base stations. This architecture has been standardized as telecommunication technologies have progressed from 1G to 2G to 3G, and is known as the dominant design among open system architectures (Davis, 1988; Davies, 1996; Steinbock, 2002).
10. The global market share of Nokia, Ericsson, and Motorola among core networks and base stations in 1998 was 12%, 29%, and 12% respectively. Among mobile handsets, these three firms had a global market share of 22.5%, 15.1%, and 19.5% respectively (Shiu and Yasumoto, 2015).
11. The global market shares of Mediatek, Qualcomm, Texas Instruments, and Infineon in 2009 for baseband chipsets were (on a shipped unit basis) 23%, 22%, 18%, and 9% respectively. Freescale and Spreadtrum market share combined with that of the other firms accounted for approximately 80% of baseband chipsets in mobile handsets. Freescale and Spreadtrum market shares are thought to have been under 9% (http://www.digitimes.com.tw/tw/rpt/rpt_show.asp?v=20101130-584#ixzz1TNoBduEp).
12. Technology specifications and essential patents are open through ETSI and 3GPP (Bekkers and Liotard, 1999). Moreover, in many cases knowledge related to the implementation of architectures in mobile telecommunications systems is held implicitly, and knowhow is kept concealed. It is therefore not an easy matter to directly measure implementation-related knowledge. Though these sorts of problems exist, if a firm in a certain technical field applies for certain patents, then it is highly likely that a firm has knowledge and knowhow indispensable to implementing technology and productization in at least that particular field.

Thus, while patents do not strictly show implementation-related knowledge, they can be an effective metric for understanding the level of ownership of "information needed for implementation".

13. The 2G GSM and 3G UMTS technology specifications database maintained by 3GPP was used (http://www.3gpp.org/ftp/Information/Databases/Spec_Status/3GPP-Spec-Status.zip). In addition, the reliability and effectiveness of the database, particularly that it contained all technology specifications, was confirmed via e-mail to 3GPP technology specifications administrator, John M. Meredith.
14. For this study, patents declared to ETSI as essential were downloaded from the global patent database on December 2012 (http://ipr.etsi.org/searchIPRD.aspx). Downloaded data included 64,228 patents from April 4, 1990 to October 2, 2012. The 3GPP 2 (Third Generation Partnership Project 2) 3G CMDA2000 standardization led by Qualcomm was excluded from this analysis, since 3G UMTS is the most-used global telecommunications standard after 2G GSM, while 3G CDMA2000 is not. Further, this paper aggregates 2G GSM, 2.5G GPRS, and 2.75G Edge as "2G GSM", and 3G WCDMA, 3.5G HSDPA, and 3.75G HSUPA as "3G UMTS".
15. In the case of technology specifications belonging to two or more telecommunications system architecture categories, the most applicable category for the technology specification was selected. By referencing 3GPP categories and technology documents with technology specifications, it became clear that the firms take into account the five categories (telecommunications services, technical issues, and plans; core network and intra fixed network; air interface; mobile phone; and security and encryption algorithms) when deciding system architecture specifications and capabilities. In addition, telecommunications system architectures within these five categories were selected for this study. Moreover, because may technology specifications related to base stations are not made public, they were included in the air interface category, the most technologically similar, in our calculations.
16. This study references "Third Generation Partnership Project: 3GPP Working Procedures" (http://www.3gpp.org/ftp/Information/Working_Procedures/3GPP_WP.pdf) and "3GPP TR 21.900 V7.2.0 (2006-06)" (http://www.qtc.jp/3GPP/Specs/21900-720.pdf) in examining the process for developing technology specifications as part of standardization activities.
17. Research confirming the flow of knowledge between firms using patent forward citations also includes Fleming and Sorenson (2001), Harhoff, Scherer and Vopel (2003). This study does not analyze backward citations for patents cited by core component supplier patents, since the focus of this study is on the outflow of knowledge from essential patents that firms have reported to the ETSI. In addition, an analysis of patent forward citations for essential patents that firms have reported to the ETSI can show the economic value of the essential patents.
18. http://www.epo.org/searching/free/espacenet.html
19. For proprietary patents of Samsung, LG, Apple, and Huawei, a keyword-based search was done on Synergytek's search engine (http://synergytek.com.tw/blog/products/ipr-search-analysis/matheo-patent/).
20. Application dates for the proprietary patents of these ten firms went beyond the most recent declared date of essential patents (October, 2012) in the essential patent data. Using the IPC (International Patent Classification: G01S1, G01S5, H01Q21, H01Q3, H04B, H04J, H04K1, H04L, H04M, H04N1, and H04Q) for Bekkers and West (2009) telecommunications patents, the total number of proprietary patents for telecommunications systems was 43,860 (approximately 13% of all proprietary patents).
21. Another reason was that the Espacenet patent database uses the same citation data for patent application numbers and publication numbers.
22. In the case of 2G GSM, the densities of technology specifications from Nokia, Ericsson, and Motorola are 0.257, 0.038, and 0.181. For 3G UMTS, these figures are 0.228, 0.096, and 0.243 respectively. These values were derived by converting correspondence relationships between technology specifications and essential patents using UCInet's "One Mode" and "Binary".
23. A similar trend was seen in the densities of technology specifications from Samsung, LG, Apple, and Huawei (see Appendix Figure A).
24. For the original data, see Appendix Table A.
25. Corresponding relationship data between technology specifications and essential patent declarations are converted to One Mode data in UCInet. UCInet's "Network/Centrality and Power/Degree (Old)" is then used to calculate the central values of technology specifications.
26. However, Table 2 shows that the central values of Qualcomm's technology specifications related to "telecommunications services, technical issues, and plans" and "air interface" are 84,319 and 148,769 respectively, 5.72 and 8.9 times those of Nokia. In that regard, Qualcomm has an even stronger control over interfaces ("telecommunications services, technical issues, and plans" and "air interface") with mobile

telecommunications systems than Nokia, Ericsson, or Motorola, and has a great deal of knowledge related to these interfaces.

27. Herfindahl index (HHI) =J, j=1(Nj/N)2, where a set of N patents falling into J patent classes, with Nj patents in each class.
28. In effect, the number of essential patent declarations from each firm is as follows: Qualcomm, 3,020; Nokia, 2015; LG 1,548; Samsung 1,347; Ericsson 1,162; Interdigital, 965; Motorola, 833; NTT docomo, 616; Huawei, 557; and Panasonic, 462.
29. In regards to other core component suppliers, Freescale had 34 essential patent declarations; Infineon, 13; and Texas Instruments, 230. Mediatek and Spreadtrum developed no technology specifications and had no essential patent declarations. Because technology specifications from Samsung, LG, and Apple numbered less than 100, these firms had a higher ratio of technology specifications to essential patents. See Appendix Table B for the original data.
30. Qualcomm has a technology specification network almost same in size as Nokia. See Appendix Figure B for more information. Qualcomm began declaring essential patents in 2000, when specifications for 3G UMTS were just being developed. In addition, the number of essential patent declarations from Qualcomm and others began to increase annually from 2005, and this coincides with revisions and corrections to 3G UMTS technical specifications (Shiu and Yasumoto, 2015). Lawsuits between Qualcomm, Nokia, and other firms regarding essential patents for mobile telecommunications became more common in 2000. This resulted in resistance to essential patents from Nokia and others, leading to Qualcomm declaring a large volume of patents as essential around 2005 (Goodman and Myers, 2005; Martin and Meyer, 2006). A more detailed analysis of how Qualcomm dealt with standardization is required in future research.
31. When analyzing patent citations, one must consider the relationship between the year in which essential patents are declared and the year in which applications are made for proprietary patents. This study posits that knowledge flow (2) is impacted by knowledge flow (1), thus making it necessary to control for whether proprietary patent applications come after essential patent declarations. Of the essential patent citations from Nokia, Ericsson, and Motorola by the six core component suppliers, the percentage of citations within one year of an essential patent declaration is about 32%. This number climbs to 59% for citations within three years of declaration. In any case, future research is required as to whether core component suppliers cite essential patents of firms promoting standardization before or after declaration of these patents in making applications for new proprietary patents.
32. Qualcomm's self-cited essential patents correspond to "core network and intra fixed network". On the other hand, essential patents cited by Nokia, Ericsson, and Motorola correspond to "telecommunications services, technical issues, and plans". Of the essential patents self-cited by Qualcomm, the percentage corresponding to technology specifications in these two categories, out of the total Qualcomm essential patents and technology specifications, were approximately 71.31% and 27.29% respectively. At the same time, of Nokia, Ericsson, and Motorola essential patents cited by Qualcommthe percentage corresponding to technology specifications in these two categories, of the total Qualcomm essential patents and technology specifications, were 21.30% and 76.82% respectively.

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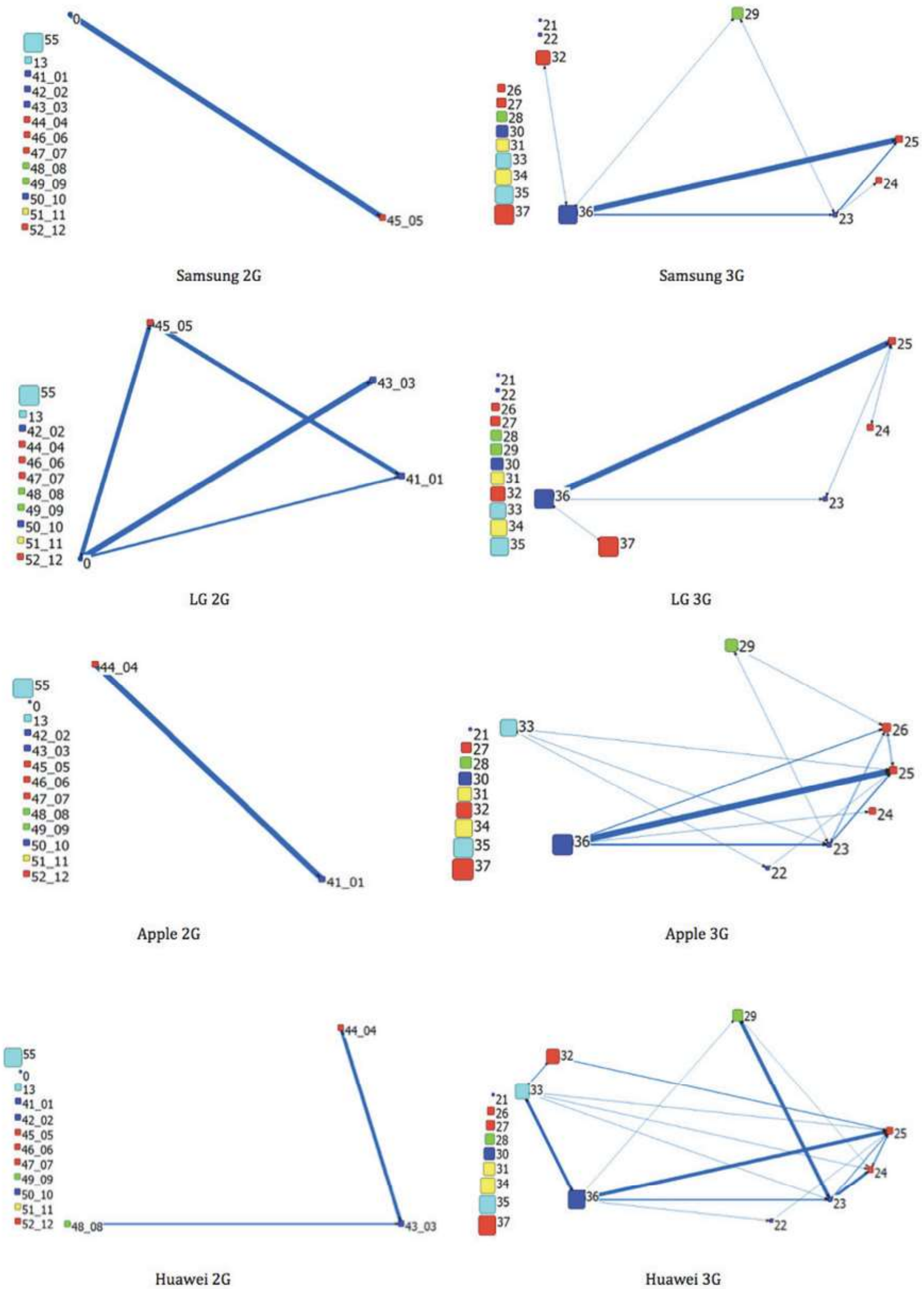
APPENDIX

FIGURE A
NETWORK DENSITY BETWEEN TECHNOLOGY SPECIFICATIONS OF NEW ENTRANT HANDEST MANUFACTURERS



	Samsung 2G	Samsung 3G	LG 2G	LG 3G	Apple 2G	Apple 3G	Huawei 2G	Huawei 3G
Density	0.01	0.051	0.038	0.037	0.01	0.096	0.019	0.118
Standard Deviation	0.097	0.221	0.191	0.188	0.097	0.294	0.137	0.322
Average Degree	0.133	0.824	0.533	0.588	0.133	1.529	0.267	1.882
Note: These values were calculated after transforming the relationships between technology specifications and essential patents by "One Mode" and "Binary" of UCInet.								

Source: Authors' analysis by using ETSI and Espacenet data

TABLE A
NETWORK DENSITY BETWEEN TECHNOLOGY SPECIFICATIONS OF NOKIA, ERICSSON, MOTOROLA, NEW ENTRANT HANDEST MANUFACTURERS, AND CORE COMPONENT SUPPLIERS

	Nokia	Ericsson	Motorola	Samsung	LG	Apple	Huawei	TI	Freescale	Infineon	Qualcomm
Density	0.212	0.05	0.194	0.016	0.018	0.038	0.038	0.002	0	0	0.208
Standard Deviation	0.409	0.219	0.395	0.126	0.133	0.192	0.192	0.045	0	0	0.406
Average Degree	6.563	1.563	6	0.5	0.563	1.188	1.188	0.063	0	0	6.438
Note: These values were calculated by using the data of 2G GSM and 3G UMTS (Europe and US) after transforming the relationships between technology specifications and essential patents by "One Mode" and "Binary" of UCInet.											

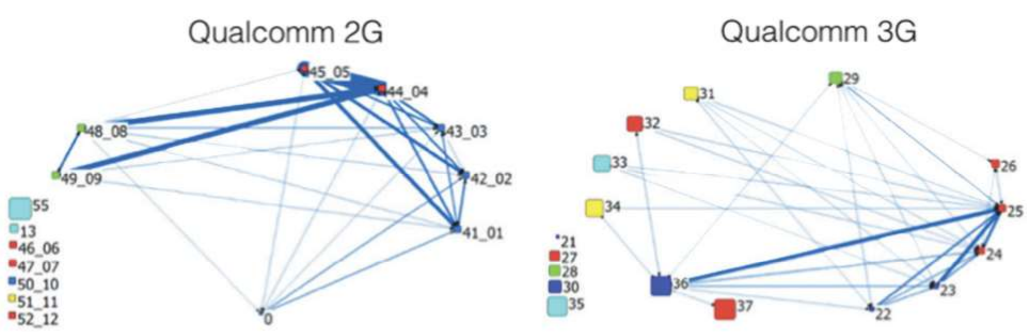
Source：Shiu and Yasumoto (2015)

TABLE B
NUMBER OF TECHNOLOGY SPECIFIACTIONS OF 2G GSM AND 3G UMTS PROPOSED BY MAJOR FIRMS

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.					

Source：Shiu and Yasumoto (2015)

FIGURE B
NETWORKS BETWEEN TECHNOLOGY SPECIFICATIONS OF QUALCOM



Source： Authors' analysis by using ETSI and Espacenet data