Kim, D.-H., Lee, H. and Kwak, J. (2017) Standards as a driving force that influences emerging technological trajectories in the converging world of the Internet and things: An investigation of the M2M/IoT patent network. *Research Policy*, 46(7), pp. 1234-1254. (doi:10.1016/j.respol.2017.05.008)

Standards as a driving force that influences emerging technological trajectories in the converging world of the Internet and things: An investigation of the M2M/IoT patent network

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Abstract

While standards are said to create windows of opportunity in facilitation of technological convergence, it is not clear how they affect technological trajectories and strategic choices of firms in the face of convergence and in the process of catch-up. There is little research on the relationship between standards and technological trajectories, particularly in the age of convergence. This paper investigates how standards shape the emerging M2M/IoT technological trajectory and influence convergence in terms of technological importance and diversity. We, firstly, found that standards are a driving force of technological convergence. The second finding is that 3GPP standards assume a crucial role in setting the boundary conditions of the M2M/IoT technological systems. Third, we identified strategic groups and strategic patents that centered around the M2M/IoT trajectory. Forth, standards serve as an important factor in the process of creating a new path for catch-up firms (e.g. Huawei). These findings make contributions to innovation and standards studies by empirically examining the relationship between technological trajectories and standards. Furthermore, they clearly cast light on ongoing cooperation and competition along the M2M/IoT trajectory, and offer practical implications for catch-up strategies.

Key words: M2M/IoT, standards, technological trajectory, catch-up

1. Introduction

The Internet of Things (IoT) has emerged as a new technological paradigm that deconstructs industrial silos, disrupts existing competitive relationships in the global markets, and opens a window of opportunity for new entrants. It is broadly expected that billions of everyday objects will be connected to the Internet within a decade and drastically affect people's daily life. In 1998, the term *Internet of Things* was coined by Kevin Ashton who described it as "a standardized way for computers to understand the real world" (Schoenberger, 2002). It embodies a vision where everyday objects with embedded sensors and actuators are seamlessly connected to the Internet, enabling "ubiquitous computing", a concept proposed by Mark Weiser in 1988. Through the embodiment of everyday life, ubiquitous computing helps people to find new ways to mobilize socio-technical assemblages (Galloway, 2004).

A variety of IoT services, based on an immense amount of data extracted from numerous sensors, are possible only when the seamless connectivity of things is ensured. Lack of communications among heterogeneous IoT networks and incompatibility among multi-layered system components are considered a technological bottleneck, constraining the current IoT evolution. A wide range of standardization activities is required to solve this problem. Such standardization efforts, accompanied with changes in architectural knowledge regarding relational properties of existing information technology (IT) systems, can have crucial impacts on a competitive landscape in the converging world of the Internet and things. Previous literature points out that there are a positive association between standards and technological importance (Rysman and Simcoe, 2008) and a negative association between standards and technological diversity (Blind, 2004). Technological importance and diversity are essential concepts to understand technological convergence (Cho & Kim, 2014). Yoffie (1997a) explained that standards played a critical role in digital convergence. However, it has not yet been clarified how standards affect technological convergence, particularly with respect to the relationship between technological importance and technological diversity. This vacancy in the literature will be addressed in this paper.

The selection of certain standards among competing technologies creates lock-in effects, and thereby influences subsequent innovations in a path-dependent manner (Arthur, 1994; Shapiro & Varian, 1999a). This path-dependence of technological evolution highlights the relationship between standards and technological trajectories for future innovations. Regarding the relationship between technological trajectories and formal standards, prior studies focus on theoretical explanations between these two concepts (Metcalfe & Miles, 1994) and the identification of technological trajectories using patents (Verspagen, 2007). Yet to the extent of our knowledge, there is no previous research that empirically shows how formal standards affect emerging technological trajectories. This research gap also needs to be filled.

Among different evolutionary trajectories of IoT (e.g. RFID, WSN, and M2M[1]), M2M is often regarded as the main pattern of IoT evolution at the present stage (Chen, Wan, & Li, 2012). There are currently a variety of standards-setting organizations and consortia (e.g. ITU, IEEE, IETF, ETSI, 3GPP, oneM2M, OIC, IIC, Thread, and AllSeen Alliance), which have

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[1] According to 3GPP (3rd Generation Partnership Project), M2M (machine-to-machine, also known as machine-type communication (MTC)) is defined as data communication among devices without the need for human interaction.

made considerable efforts to accelerate the development of M2M/IoT standards (Schneiderman, 2015).[2] During the period of technological paradigmatic transition, a strategic decision as to which standards to choose critically affects firms' future performance due to issues of compatibility. Bound to a common fate in the era of an emerging technological paradigm, firms with similar technological capabilities are likely to form strategic alliances and interact in a cooperative and competitive manner (Gnyawali & Park, 2011; Nohria & Garcia-Pont, 1991). Catch-up firms, in particular, are sensitive to the setting of standards in the time of a techno-economic paradigmatic shift, as new standards bring technological challenges and opportunities. Accordingly, a fleet of firms, including catch-up firms, have been vigorously involved in the process of setting M2M/IoT standards to affect the direction of technological change. In this context, the investigation of an M2M/IoT trajectory can be utilized to identify strategic patents and strategic groups, which have a high potential for strategic alliances. This will help us to understand the dynamics of strategic competition, revolving around the M2M/IoT trajectory, in the catch-up context.

In our paper, we have the following main research objectives: 1) to demonstrate how standards affect technological convergence in terms of technological importance and technological diversity; and 2) to examine whether standards hold a crucial role in the shaping of the M2M/IoT trajectory and, if so, which standards are significant. Furthermore, we attempt to identify strategic patents and strategic groups that center around the M2M/IoT trajectory. To this end, we rely on the dataset of M2M/IoT patents and the methodologies of social network analysis, main path analysis, patent text similarity analysis, and clustering analysis. Findings from these analyses are expected to fill the aforementioned research gaps, contribute to the theoretical understanding of the relationship between standards and innovation, and offer practical implications.

As for the structure of the paper, the subsequent section contains the review of prior literature on M2M/IoT as a large technological system, the relationship between technological trajectories and standards, and the relationship between standards and patents. Section three describes our research methodology and data collection. We then present the findings and discussion of this research in sections four and five. Thereafter, the paper is concluded with the clarification of its findings and limits.

2. Literature Review

2.1. M2M/IoT as a large technological system

The IoT encompasses an ensemble of heterogeneous technologies, standards and subsystems labeled with reference to three different paradigmatic visions (i.e. things-, Internet-, and semantic-oriented) (Atzori, Iera, & Morabito, 2010). The system of interconnected artifacts has been evolving in a way to not only extract information from the environment (sensing) and interact with the real world (actuation/command/control), but also draw on Internet standards to offer services for data analytics and applications. The main objectives of this technological system are apparently to embed intelligence into the environment, enable

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[2] The full names of IoT technologies and standards-setting organizations and consortia are noted in Appendix 2 (glossary).

ubiquitous computing without human intervention and vanish the presence of technologies from the consciousness of people in daily life. To this end, smart connectivity with existing networks and context-aware computation using network resources are indispensable (Gubbi, Buyya, Marusic, & Palaniswami, 2013).

Current IoT research predominantly focuses on the technical aspect of IoT, particularly with respect to system architectures and networks. For instance, Shen & Carug (2014) argued that the existing architecture reference models (e.g. Open System Interconnection (OSI) and Next Generation Network (NGN)) are not suitable for IoT, suggesting a new reference model for IoT standardization. Zhou (2012) introduced a four pillar of IoT (i.e. M2M, RFID, WSN and SCADA) categorized by different IoT networks.[3] Yet some scholars (e.g. Shin (2014)) viewed IoT as a socio-technical system in which the social and technical aspects of IoT are intertwined in a complex manner. From this perspective, it is of significance to investigate the historical development of IoT technologies within the social context in which they are embedded (Bijker, 1995). As Pinch and Bijker (1987) pointed out, those technological problems were defined within the context of meaning assigned by relevant social groups. Hughes (1983), for example, probed into the history of the electric power system development in Western society, and revealed how artifacts were socially constructed to become the components of a large technological system.

Standards serve as a medium of coordination among technological artifacts and social actors (Schmidt & Werle, 1998). Through the processes of social negotiation, consensus formation and legitimacy seeking, a number of interests of heterogeneous stakeholders are coordinated and inscribed into standards (de Vries, Verheul, & Willemse, 2003). Standards-setting committees and their institutional rules offer arenas in which actors negotiate and contextualize their decision-making processes. Issues regarding compatibility between components in the system and balance in their performance capabilities have been crucial in the standards-setting process of emergent network technologies, driven by various social actors (David & Bunn, 1988). The development of M2M/IoT as a large technological system particularly necessitates committees-based compatibility standards, which specify the relational properties of technological artifacts embodied in the system of M2M/IoT patents.

Within a large technological system, the functioning of one subsystem is greatly affected by its system architecture and complementary subsystems. Technological imbalances between system elements critically retard a system improvement process (Rosenberg, 1969). Similarly, Hughes (1987) used the term *reverse salients* (i.e. "components in the system that have fallen or are out of phase with others", p. 73) to describe a set of critical problems in need of attention for system growth. The sequential patterns of problem-solving activities arising from interdependencies among components in a large technological system (i.e. a change in one part becomes a problem in other parts) and the significance of compatibility naturally lead to the necessity of understanding the path-dependent development (like trajectories) of technologies and the role of standards.

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[3] WSN (wireless sensor network) refers to a system of sensors interconnected mostly through the short-range wireless mesh networks (e.g. Zigbee). While WSN put an emphasis on data gathering from numerous sensor nodes and unidirectional data transfers to servers via gateways, M2M networks tend to focus on device control through bidirectional communications between devices and servers (H. Kim, 2014). SCADA (supervisory control and data acquisition) refers to a smart system, based on closed-loop control theory, which connects equipment mostly via wired short-range networks (e.g. field buses).

2.2. Technological change, trajectory and catch-up opportunities

Technological change, propelled by a series of problem-solving activities, is often explained from the evolutionary perspective of variation, selection and retention (e.g. Nelson & Winter, 1982). The process of variation and selection, in particular, is greatly influenced by a technological paradigm—"a 'model' and a 'pattern' of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies" (Dosi, 1982, p. 152). An italic emphasis on *selected* indicates that the context of choosing relevant problems and appropriate solutions in which a group of people, such as engineers, are embedded constitutes the core of a technological paradigm. This concept is linked to Nelson and Winter's (1977) heuristic search processes—"a set of procedures for identifying, screening, and homing in on promising ways to get to [an activity's] objective or close to it. The procedures may be characterized in terms of the employment of proximate targets, special attention to certain cues and clues, and various rules of thumb" (pp. 52–53). By delineating the boundaries of perceivable technological possibilities, a technological paradigm steers the possible directions of technological change.

Due to the cumulative, irreversible nature of technological change, technology advances along a technological trajectory—"the pattern of 'normal' problem solving activity (i.e. of 'progress') on the ground of a technological paradigm" (Dosi, 1982, p. 152). This pattern emerges through the improvement of multi-dimensional trade-offs among variables with technical, process, service characteristics (Saviotti & Metcalfe, 1984) in a socially constructed design space. Given that technology is the embodiment of useful knowledge—a combination of propositional (how nature works) and prescriptive (how to use techniques) knowledge (Mokyr, 2002)—with reference to problem-solving activities, a technological trajectory can be represented by the main flow of knowledge predicated upon a technological paradigm. Recently, some researchers (e.g. Martinelli, 2012; Verspagen, 2007) attempted to identity technological trajectories via top paths in patent citation networks, considering a patent is a useful proxy for engineering knowledge.

Changes in technological systems and techno-economic paradigms affect the cost of entry in a market and opens catch-up opportunities for *de novo* entrants (Perez & Soete, 1988). The paths of technological evolution assume a significant role in catch-up since many latecomer firms set different types of catch-up strategies grounded on technological trajectories: path-creating, path-skipping and path-following catch-up (Lee & Lim, 2001). Standards offer latecomer firms an opportunity to catch up. By consolidating the meaning of a technical artifact into a common understanding (i.e. "closure" in Bijker's (1995) term), standards shape technological trajectories by stabilizing the variations of technological change and channeling them into a certain direction. By developing standards as guideposts for the evolutionary pattern of problem-solving activities, the tyranny of combinatory explosion in a multi-dimensional design space will be reined (Metcalfe & Miles, 1994). When standards, which affect the rate and direction of technological change, are fixed, there is less risk of choosing which technological trajectory latecomer firms enter and it is easier for them to produce complementary goods and services (Greenstein & Khanna, 1997; Lee, Lim, & Song, 2005). Latecomer firms from late-industrialized countries (e.g. South Korea and China) have strategically utilized standards not only to follow the paths of forerunners, but to achieve stage-skipping and path-creating catch-ups, particularly in ICT-related industries

(Lee et al., 2005; Mu & Lee, 2005). This stream of literature highlights the strategic importance of the M2M/IoT technological trajectory shaped by standards.

2.3 Standards and patents

Depending on coordination mechanisms, standards can be roughly classified into de facto standards (market) and formal standards (committee) (David & Greenstein, 1990). Formal standards are established through the processes of discussion, negotiation and consensus-based agreement by interested parties, while de facto standards are produced via the process of a dynamic bandwagon in the market without formal agreement or even discussion (Farrell, 1989). Formal standards, in particular, accentuate the processes of negotiation among relevant social actors and of consensus with respect to the meaning of technological artifacts. De facto standards (or dominant designs) put emphasis on technological dominance in a market (Suarez, 2004).

Standards are often regarded as “public goods” (i.e. non-rivalrous and non-excludable according to Samuelson's (1954) criteria) (Kindleberger, 1983). Patents, by contrast, are defined as a set of exclusive rights granted to inventors in return for public disclosure of inventions. Earlier studies have focused on this inherent tension between standards and patents. Farrell (1989) explained how the protection of intellectual property, such as patents, affects the processes of formal and de facto standardization. Strong patent protection, as he points out, may retard formal standardization, in particular, due to an increase in vested interest. Accordingly, many standards-setting organizations (SSOs) set their rules that influence the patenting behaviors of firms by obligating their participatory members to declare patents that are essential to the implementation of standards (Lemley, 2002).

Recent studies have delved into the value of the (declared) standards-essential patents (hereinafter “essential patents”). Rysman and Simcoe (2008) found that essential patents receive more citations over a longer period of time, as compared to non-essential patents. They also showed that there is a substantial increase in the forward citations of essential patents after the disclosure to the SSOs, demonstrating the marginal effect of an SSO endorsement on the value of patents. Bekkers, Bongard, and Nuvolari (2011) demonstrated that, in comparison with the intrinsic technological value of the patents, a strategic involvement in the process of standardization serve as a stronger determinant of essential patents in the case of WCDMA. Similarly, the findings of Kang and Motohashi (2015) showed that the attendance of inventors to the standardization meetings is a key determinant of essential patents.

A strong patent portfolio is viewed as one of the key assets to win a standards competition by bolstering a firm’s position in the standards negotiations (Shapiro & Varian, 1999a). Opportunities to flex their muscles in the negotiations of standards development may incentivize firms to engage in active patenting activities (Gandal, Gantman, & Genesove, 2007). For instance, leveraging its large portfolio of essential patents, Motorola was able to exert a formidable negotiation power in the process of the GSM standardization (Bekkers, Verspagen, & Smits, 2002). Intriguingly, Blind and Thumm (2004) found that firms with higher patent intensities tend not to join the process of formal standardization, indicating that technological advantages based on strong patent portfolios may guide firms to pursue de facto standardization. That is to say, a great patent portfolio gives a firm the upper hand in a knowledge position, empowering it to make various strategic moves. With the respect to knowledge positions in standards-based high-tech markets, Bekkers and Martinelli (2012) showed that link connectivity based on the measure of traversal counts in the top main paths is a better indicator than the simple counts of essential patent families. These earlier studies lend support to the investigation of an M2M/IoT technological trajectory as a means to understand firms' technology strategies.

To the best of our knowledge, there are very few studies that have investigated citations to non-patent literature (NPL) as a linkage between standards and patents, while some past research has discussed the role of science in patents through the examination of references to NPL. Citations to NPL have been used as an indicator to operationalize the dependence of technology on science. As Tijssen (2001, p. 52) remarked, "these citations at the very least indicate an awareness of scientific results with some indirect bearing on elements of the invention. In the best case, they reflect strong evidence of substantial direct contributions of scientific inputs to breakthrough technological innovations." Fleming and Sorenson (2004) found that references to science can be of great use when inventors give an attempt to solve difficult problems involving the combination of highly coupled (i.e. non-modular) components. These science linkages work as part of the context in which technological innovations are to be situated (Narin, Hamilton, & Olivastro, 1997). This logic underneath NPL as a science linkage to patents is similarly applicable to the relationship between standards and patents. Rysman and Simcoe (2008), for instance, regarded patents referencing to IETF standards in their non-patent literature as reflecting platform technologies in that those patents are more likely to build upon the Internet standards.

Assumed that standards influence the shaping of a technological trajectory, which can be identified by a main path in the patent citation network, patents citing standards are more likely to serve as a base for subsequent technological changes. The basicness of patents can be operationalized by two indicators: importance and generality (Trajtenberg, Henderson, & Jaffe, 2002). The importance can be measured by the number of forward citations, while the generality can be calculated by the Herfindahl index on technological classes of citing patents.[4] Within the field of network technologies where compatibility assumes a critical role (David & Steinmueller, 1994), patents referencing to standards that ensure compatibility are likely to be grounded upon core knowledge that is fundamental to interoperability within a large technological system, and thereby receive more citations. Accordingly, the following hypothesis can be derived:

H1: a reference to standards is positively associated with the importance of patents.

Standards offer a function of variety-reduction that assists industry players in mitigating risks and achieving focus, which is critical to scale economies-based market expansion (Blind, 2004). By optimizing the variety of technologies and selecting dominant designs, standardization works as the process of freezing technological frames and ushering a technology cycle into the era of incremental change (Anderson & Tushman, 1990). Standards,

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[4] According to Trajtenberg et al. (2002), generality refers to the extent to which subsequent technologies are spread across different fields, rather than being concentrated in just a few of them.

$\text{GENERAL}_i = 1 - \sum_{k=1}^{Ni} (\frac{\text{NCITING}ik}{\text{NCITING}i})^2$ where k is the index of patent classes (IPC), and N_i is the number of different classes to which the citing patents belong.

selected by industry players as a part of technological infrastructure, generate self-reinforcing mechanisms and lock-in effects, and thereby may hamper flexibility (Arthur, 1994; Hanseth, Monteiro, & Hatling, 1996). This means that standards-citing patents are more likely to have lower generality values, which represent higher concentration in a specific technological field. Hence, we drew the following hypothesis:

H2: a reference to standards is negatively associated with the generality of patents.

Patent citation networks have been used to investigate the evolutionary patterns of technological convergence. The convergence of heterogeneous technologies often propels the driving forces of technological change. Technological convergence is defined as "the process by which two hitherto different industrial sectors come to share a common knowledge and technological base" (Athreye & Keeble, 2000, p. 228). For instance, common processes were shared among different machinery sectors (Rosenberg, 1976), and certain generic technologies were imperatively used as an essential base for product innovation in a number of the world's largest firms (Patel & Pavitt, 1997). The convergence of information and communications technologies (ICT) has been driven by sharing the standards of common network architectures. GSM (2G) and UMTS (3G) standards, for example, assumed a critical role in the emergence of new technological trajectories in the mobile telecom industry, generating market potential for strategic alliances to add new services compatible with the shared network standard (Sadowski, Dittrich, & Duysters, 2003).

The similar structures of convergence in the spheres of patents and standards indicate a correlation between technological development and standardization (Gauch & Blind, 2015). Patents related to services adapted for wireless communication networks (IPC H04W4/00), in particular, among essential patents have held a central position in technological convergence in ICT standards (Han & Sohn, 2016). The degree of attraction and that of technological diversity have been employed to measure technological convergence in patent citation networks (Cho & Kim, 2014). The importance of patents and the generality of patents correspond to the degree of attraction and that of technological diversity, respectively. Since standards serve as a base of technological convergence, the following hypothesis can be derived:

H3: a reference to standards moderates the relationship between the importance of patents and the generality of patents.

3. Methodology

3.1. Patent citation-based communities and main path analysis

Patents have been long recognized as a rich data repository for the study of technological change. Patent citation data (backward citations refer to the number of cited documents and forward citations refers to that of citing documents) enable epistemic linkages to be traced in a technological field. The premise underlying patent citation analysis is that highly cited patents may contain essential technological advances which later technologies are built upon (Karki & Krishnam, 1997). This possibility is predicated on a cumulative and irreversible view of technological progress, by which inventions are influenced by prior arts and in turn contribute to the knowledge base for future inventions (Jaffe & Trajtenberg, 2002). In this sense, the network of patent citation data may reflect the dynamics of technological evolution at a knowledge level. Particularly in industries where technological systems are deeply interdependent, the network analysis of patent citations can be of great use to discover core and emerging technologies, which is vital for technology strategy formulation (Cho & Shih, 2011).

The techniques and software packages of social network analysis are frequently used to examine and visualize patent citation networks. The social network analysis conceptualizes individual patents as nodes and their citation relations as lines, and reveals the structural properties of a patent citation network via several measurement indicators (e.g. centrality) and the graphical representation of the network (Wasserman & Faust, 1994). In addition, the modularity optimization method (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008) was employed to identity communities in the patent citation network. This method finds optimal values by measuring the density of links *inside* communities as compared to links *between* communities. Among centrality indicators, betweenness centrality was primarily used to identify the main flow of knowledge in a technological field. It measures the number of shortest paths from all nodes to others that pass through a particular node (Freeman, 1977). Assumed that the transfer of knowledge more frequently occurs along the shortest paths, the citation network of patents with high betweenness centrality may map the bedrock of an evolving technological field within an epistemic context. As with previous research (Leydesdorff, de Moya-Anegón, & Guerrero-Bote, 2015), we used Gephi to visualize the citation network of M2M/IoT patents and calculate network indicators, including betweenness and closeness centrality (Freeman, 1979) and modularity (Blondel et al., 2008).

For the crystallization of the M2M/IoT trajectory, one of the Hummon and Dereian's (1989) connectivity measures (i.e. Search Path Node Pair (SPNP)) was employed to identify the top path in the M2M/IoT patent citation network. This connectivity algorithm calculates a weight value assigned to each citation link based on its relative position in the overall network structure. If the SPNP value of a particular link is 21, for instance, it means that link connects a total of 21 pairs of nodes.[5] The top path can be identified by tracing the nodes with the highest SPNP value from sources (i.e. starting points—patents that do not cite any other patents) to sinks (i.e. end points—patents that do not receive any citations). In several research papers (e.g. Fontana, Nuvolari, & Verspagen, 2009; Verspagen, 2007), this path is considered the critical backbone of knowledge flow, representing a main technological trajectory.

As with prior studies (Fontana et al., 2009; Martinelli, 2012), we used Pajek to calculate the SPNP values and identify the top path of the M2M/IoT patent citation network. The main research objectives will be addressed by carefully examining whether patents lying on the main path of the M2M/IoT trajectory.

3.2. Patent similarity-based clustering analysis

Patents reflect firms' technological capabilities to innovate. Firms with similar technological capabilities often take form as a strategic group and similarly act in the face of uncertainty (Nohria & Garcia-Pont, 1991). Yet patent text similarity raises the risk of potential patent

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[5] For the details of the calculation method of SPNP, see Fontana, Nuvolari, & Verspagen (2009).

infringement lawsuits, intensifying competition between firms with similar patents (Bergmann et al., 2008). That is to say, firms with similar patents are likely to interact in a simultaneously cooperative and competitive (coopetitive) manner (Brandenburger & Nalebuff, 1996).

Latent semantic analysis (LSA), based on singular value decomposition (SVD), has often been used to examine patent text similarity (Han & Sohn, 2015). LSA is a mathematical computation-based method for extracting the aggregate of word contexts, which determines the similarity of words (Landauer, Folt, & Laham, 1998). Lee and his colleagues' research demonstrated that the performance of the LSA model is consistent with human judgments of similarity (Lee, Pincombe, & Welsh, 2005). We employed LSA to derive patent text similarity estimates and identify strategic groups of firms that center around the M2M/IoT trajectory.

We extracted terms from the title, abstract and main claim of patents,[6] and then preprocessed the text data by first transforming the terms to lower-case letters, second removing numbers, punctuation, words of length less than three and stop-words, and third stemming the terms. Thereafter, a term-document matrix was generated based on the occurrences of terms in patents. The weighting of terms is applied to dampen the effects of frequent terms in each patent and amplify the effects of infrequent terms across the patents. Log frequency weighting is employed for local weighting, whereas entropy term weighting is used for global weighting.

Using R, the software commonly used for statistical analysis, we created a latent semantic vector space from the term-document matrix. To normalize ratio-scaled values, we divided each value of the column by the square root of the column sum of squares of all values. Cosine similarity was used to calculate the similarity of patents. Thereafter, Ward's hierarchical agglomerative clustering method was applied to identify patent clusters based on patent text similarity. Ward's minimum variance criterion was employed to detect clusters with minimal within-cluster variances (Ward, 1963). We considered these clusters as strategic groups in a coopetitve manner.

3.3. Variables

The influence of formal standards on the shaping of a technological trajectory can also be demonstrated by testing the aforementioned hypotheses (H1, H2, & H3). The technological trajectory is operationalized by a network of patent citations, and the linkage between formal standards and patents is measured by a patent citation to standards in non-patent literature. Therefore, a binary variable indicating whether patents reference to standards (Standards) is the main independent variable (IV) in this research. For H1, the importance of patents is measured by the number of forward citations (Trajtenberg et al., 2002). Carpenter, Narin, & Woolf (1981) demonstrated that technologically important patents underlying products with industrial awards are more highly cited than a control group of randomly selected patents. Similarly, the findings of Harhoff, Scherer, & Vopel's (2003) research showed that the count of citations received from subsequent patents is positively related to the patent's value, estimated from a survey of patent-holders. Older patents tend to receive

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[6] As for the text of standards, we used terms from the title, scope, and overview of standards.

more citations than newly published patents. To prevent a bias arising from the age effect, we divide the number of forward citations by the average number of forward citations in the same application year (Hall, Jaffe, & Trajtenberg, 2001).

For control variables, the number of backward citations (Backward citations) was first taken into account. This may reflect the dependence on prior technologies and the cumulativeness of a patent (Cassiman, Veugelers, & Zuniga, 2008). Previous research (e.g. Harhoff et al., 2003) showed that backward citations are positively associated with a patent's value, which is also correlated with forward citations. It is because the more a patent is within the local search domain of other firms via direct connections to other patents (i.e. backward citations), the more likely the patent to serve as a base for boundedly rational firms' search for future technology (Podolny & Stuart, 1995). For firm-specific variables, we added the number of employees, the number of patents granted in USPTO and R&D expenditures as proxies for firm size and general technological assets (LnFirmSize, LnIP, LnR&D) (Bekkers et al., 2011; Kang, Huo, & Motohashi, 2014; Leiponen, 2008). Larger-sized firms with greater technological potential have favorable conditions in making more valuable innovations (Schumpeter, 1950). Those numbers were rescaled by taking the natural logarithm. Whether firms are founded in catch-up economies was also factored in as a dummy variable (Catch-up). European and US firms have been holding strong knowledge positions, which are crucial to produce technologically important patents, particularly in the field of mobile communications (Bekkers & Martinelli, 2012). Firms in latecomer countries (such as Korea and China) have traditionally relied on external knowledge from European and US firms, yet have recently employed technology standards to catch up (Kang et al., 2014). Application years were inserted as dummy variables to capture any residual temporal effects (Year).

For H2, the generality of patents is measured by the Herfindahl index on technological classes of citing patents (Generality) (Trajtenberg et al., 2002). This variable indicates how much a patent is cited by subsequent patents from various technological fields, reflecting technological diversity. Its value ranges from 0 (extremely specific) to 1 (extremely general). For control variables, originality was taken into consideration. Originality is the backward citation measure, equivalent for generality, indicating the broadness of a patent's technological root (Originality). If a patent cites prior research from a wider range of technological fields, its originality gets close to one. Previous studies (e.g. Trajtenberg et al., 2002) show that originality breeds generality. The number of forward citations was also factored in (Forward citations). Where a patent receives more subsequent citations, there is a built-in tendency to cover more technological classes (Hall et al., 2001). A catch-up firm dummy variable is inserted as well. Given R&D resource constraints, firms in catch-up economies tend to strategically select and concentrate on a specific technological field (Park & Lee, 2006).

The Tobit model was mainly used to test the aforementioned hypotheses (H1: the number of adjusted forward citations as a dependent variable (DV) (Kang et al., 2014); H2: the generality of a patent as DV (Cassiman et al., 2008)). This model is often employed to describe the relationship between IVs and a non-negative DV, in which the observations take rational numbers and are bounded below by zero. The Tobit model assumes the homoscedasticity and normal distribution of residuals. Powell's (1984) method for censored least absolute deviations (CLAD) is often used to estimate the effect of IVs on the conditional median of DV in the case of the violation of those assumptions, since this non-parametric regression method is robust to such violation (Sampat & Ziedonis, 2004). We also performed robust checks, relying on the Powell's CLAD estimator with 200 bootstrap replications. For H1, the number of (non-adjusted) forward citations is additionally considered as DV. The Poisson regression model is first considered for count data with non-negative integer values where being cited is an event with a probability of success (Cameron & Trivedi, 1998). Yet in the case of violation of the equipdispersion assumption (i.e. the variance is equal to the mean), the negative binomial (NB) regression model is taken into account (Hausman, Hall, & Griliches, 1984). After the overdispersion test, we drew on the NB model for the number of forward citations.

For H3, the importance of patents is modified to measure the binding force of a technology, a source of attraction for technological interaction (Binding force). Closeness centrality is used as a proxy variable for the binding force (gravity concept), which explains how each node is cohesively connected to the others (Cho & Kim, 2014). Following the gravity model, the importance of a patent (the count of adjusted forward citations) was weighted with the square of the patent's closeness centrality. A high binding force indicates a patent with high degree centrality and high closeness centrality. A strong correlation between binding force (source of attraction) and generality (technological diversity) results from technological convergence.

Subgroup analysis was performed to probe into the moderating role of standards (Sharma, Durand, & Gur-Arie, 1981) in the relationship between the binding force and generality. The dataset was split into two subgroups: a group of patents without a reference to standards (STD=0) and that with (STD=1). A moderation test was conducted to find statistical differences between the two groups in the regression coefficients of generality on binding force from the Tobit model. As with previous research (Cameron & Trivedi, 1998), we employed Stata to conduct a statistical analysis of count data. We also used R to cross-checked the test results.

3.4. Data

For data collection, US patent data was extracted from WIPS, one of the largest online subscription-based patent databases in South Korea. We double-checked the accuracy of patent data by matching it with data from the database of USPTO (United States Patent and Trademark Office). US patent data has been widely used to investigate the dynamics of innovation under the assumption that it reflects technological developments worldwide (Erdi et al., 2013). US patent citations are particularly valuable due to the duty of candor under the US patent law, which includes that a failure to disclose relevant prior art may render any ensuing patent unenforceable (Erstling, 2011; Gay, Le Bas, Patel, & Touach, 2005).

The Cooperative Patent Classification (CPC) code[7] H04W4/005 (mobile application services or facilities specially adapted for wireless communication networks for machine-to-machine communication [M2M, MTC]), was used to set the patent search scope. The number of granted M2M/IoT patent has rapidly increased in recent years. In 2014, there were 235 granted M2M/IoT patents under the CPC code H04W4/005. Yet as of November 16, 2016, a

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[7] CPC, as an extension of the International Patent Classification (IPC) code, has been jointly developed by the USPTO and EPO (European Patent Office).

total of 1203 granted M2M/IoT patents were searched under the same code. This makes evident that M2M/IoT is a newly emerging, fast-growing technology field. In this paper, we used 588 M2M/IoT patents, which were granted before the year 2016, and extracted their backward/forward citation data. In total, 5,425 patent citation data was used to visualize and analyze the M2M/IoT patent citation networks.

The dataset of granted patents is subject to the truncation issue (i.e. missing observations of patents filed in recent years that have not yet been granted) (Hall et al., 2001), as shown in Figure 1. In particular, the forward citations of recently applied patents may not be fully observed as a result of truncation. To minimize the problem of truncation, we select five years' patents with application years, ranging from 2008 to 2012, for the statistical analysis. A past five year window has been used to measure the current impact index (Karki & Krishnam, 1997). The application year 2008 is the year when formal standards with respect to M2M/IoT were first cited in the M2M/IoT patents. From Compustat via WRDS[8] and the USPTO database, we retrieved data on the average number of employees, the average R&D spending and the average number of patents granted in USPTO over the period 2008–12 for the firms included in our dataset. The descriptive statistics of the patent data over the period 2008–12 is presented in Table 1. The correlation matrix is shown in Table 2.

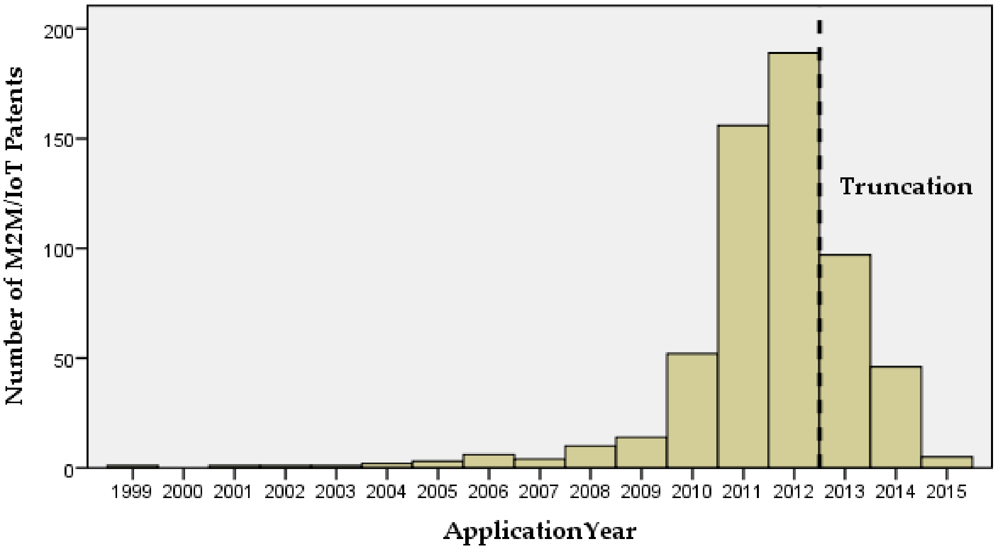

Figure 1. Number of granted M2M/IoT patents

Table 1. Descriptive statistics of the patent data over the period 2008–12[9]

Variable	Description	Obs.	Mean	SD	Min.	Max.
Standards	Dummy on whether a citation is made by a patent to a formal standard	421	0.49	0.50	0	1
Forward citations	Count of citations that a patent receives from subsequent US patents	421	2.93	5.86	0	56
Adjusted forward	Number of forward citations divided	421	1.00	2.06	0	28.65

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[8] https://wrds-web.wharton.upenn.edu/wrds/

[9] The IPC classes of foreign patents that cited, and were cited by, M2M/IoT patents were included to measure generality and originality.

citations	by the average number of forward citations in the same application year					
Generality	Herfindhal index (IPC classes) on forward citations	253	0.44	0.25	0	0.91
Originality	Herfindhal index (IPC classes) on backward citations	253	0.65	0.20	0	0.93
Binding force	Count of adjusted forward citations weighted with the square of closeness centrality	376	0.71	1.74	0	27.65
Backward citations	Count of citations made by a patent to prior US patents	421	20.62	70.88	0	1209
Catch-up	Dummy on whether firms are from catch-up economies (i.e. Korea, China and Taiwan)	421	0.31	0.46	0	1
LnFirmSize	Natural log of average employees	394	10.25	2.33	0.69	12.94
LnIP	Natural log of average US patents	414	7.01	2.39	0	10.17
LnR&D	Natural log of average R&D expenditures	344	21.46	1.69	14.82	24.21

Table 2. Correlation matrix

	STD	FCITE	GEN	ORI	BIND	BCITE	CAT	SIZE	IP
STD									
FCITE	–0.05								
GEN	–0.22	0.27							
ORI	–0.23	0.18	0.37						
BIND	–0.04	0.23	0.20	0.10					
BCITE	–0.14	0.52	0.21	0.16	0.75				
CAT	0.19	–0.09	–0.35	–0.28	–0.11	–0.11			
SIZE	0.13	–0.15	–0.14	–0.09	–0.09	–0.19	0.17		
IP	0.21	–0.03	–0.23	–0.11	–0.03	–0.08	0.32	0.64	
RD	0.02	–0.16	0.11	–0.01	–0.07	–0.05	–0.11	0.72	0.69

STD: Standards, FCITE: Forward citations, GEN: Generality, ORI: Originality, BIND: Binding force, BCITE: Backward citations, CAT: Catch-up, SIZE: LnFirmSize, IP: LnIP, RD: LnR&D.

4. Findings

4.1. M2M/IoT communities and strategic patents

Drawing upon the Gephi software, we visualized the overall M2M/IoT patent citation network structure, as shown in Figure 2 (Left). This figure shows that there is a giant component, consisting of several clusters, in the center of the M2M/IoT patent citation network. It is obvious that some patents serve as strategic linkages that connect different clusters in the giant component. By relying on modularity optimization (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008),[10] we identified ten different communities in the giant component of the M2M/IoT patent citation network, as shown in Figure 2 (Right).

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[10] We set ten as a resolution limit on the size of the smallest community.

Modularity measures the fraction of edges within communities (i.e. clusters or modules) as compared to the expected fraction of such edges placed at random.[11] It is used to identify densely connected groups of nodes with sparse edges between groups, which reflects community structure in a network. A good partition of communities refers not merely to one in which there are few edges between communities, but to one in which there are fewer than expected edges between communities (Newman, 2006). Using modularity as a goodness measure of community structure is one of the most popular community detection methods (Fortunato, 2010). Blondel et al.'s algorithm, first, optimizes modularity by allowing only local changes of communities over all nodes, and then aggregates the found communities in order to find a global maximum of modularity (Blondel et al., 2008).

The modularity of the top ten communities in the giant component of the M2M/IoT networks is above 0.8. Generally, above 0.3 is considered a good indicator of significant community structure in a network (Clauset, Newman, & Moore, 2004). The significant structure of the top ten communities can also be confirmed by the visualization of the densely connected groups of nodes with sparse edges between communities in the M2M/IoT network, as manifested in Figure 2. This means that patents in the same community share the same backward citations or forward citations, and thereby contain similar information. Therefore, each community corresponds to a specific type of technology that is distinct from one another. The emergence of this technology community takes place since firms with similar strategic interest cite similar standards or patents. These communities can also be considered as strategic blocks, which are based on similar linkages (Nohria & Garcia-Pont, 1991).

For the verification of the community detection results, we used a different algorithm (i.e. Chinese Whispers) to check whether similar community structure is identified in the network. The Chinese Whispers (CW) algorithm is used to find groups of nodes that deliver the same information to their neighbors (Biemann, 2006). Similar with Blondel et al.'s modularity optimization method, the CW algorithm works in a bottom-up fashion. Each node inherits the strongest class (or information) in its neighborhood (i.e. the class whose sum of edge weights to the given node is maximal). A group of the same class (i.e. cluster) stabilizes during the iteration, and its boundary expands until it meets the border of another cluster. By employing the CW algorithm, we found the cluster structure that is similar with the one identified via Blondel et al.'s approach, as shown in Appendix 1. The only noticeable difference is that the CW algorithm could not group together nodes within the first community identified by Blondel et al.'s method. This implies that the first community contains relatively inhomogeneous information as compared to other communities.

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[11] It is defined as $Q = \frac{1}{2m}\sum_{i,j}[A_{ij} - \frac{k_i k_j}{2m}]\delta(c_i, c_j)$, where A_{ij} represents an element of an adjacency matrix whose value is 1 if nodes i and j are connected and 0 otherwise, $k_i (= \sum_j A_{ij})$ is the sum of the edges attached to node i, c_i is the community to which node i is assigned, the δ-function $\delta(u, v)$ is 1 if $u = v$ and 0 otherwise, and m $(= \frac{1}{2}\sum_{i,j} A_{ij})$ is the total number of edges in a network. $\frac{k_i k_j}{2m}$ is the probability of an edge existing between nodes i and j if connections are made at random but respecting node degrees (Clauset et al., 2004).

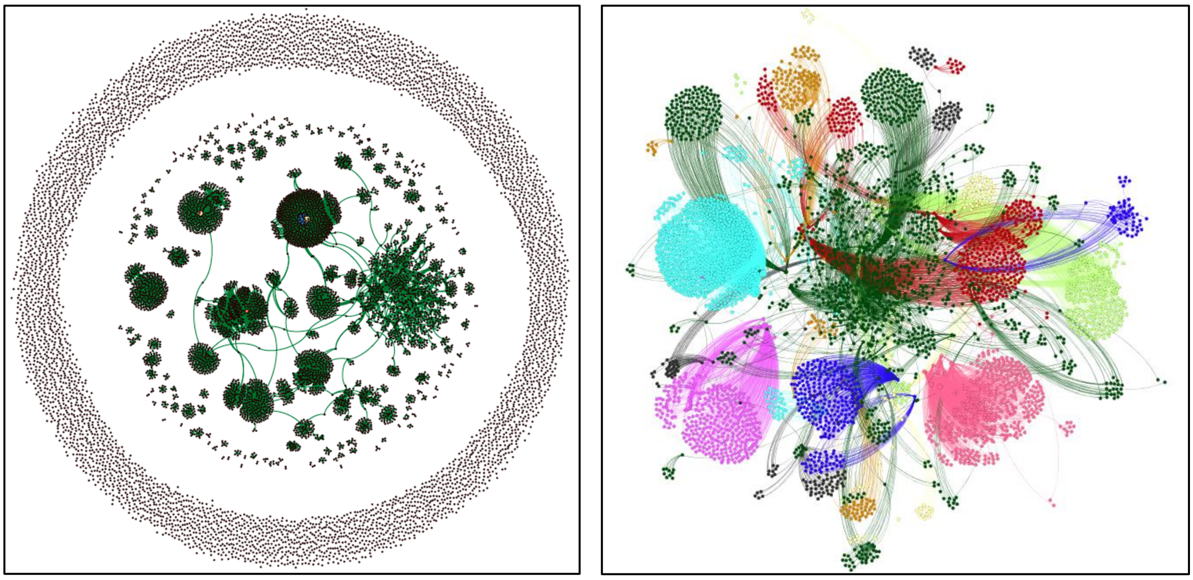

Figure 2. The overall citation network structure of M2M/IoT patents (Left) and top 10 communities (Right)

The community detection method is of great use to discover nodes which hold a central position within each community and those which serve as bridges between communities. Relying on betweenness centrality, we extracted the top ten patents with a central position within each community in the M2M/IoT patent citation, as shown in Table 3. In the first community, which is the largest cluster and colored green, several different firms are connected, and, in turn, there is no single dominant firm. In the second community, colored sky blue, Seven Networks and Intel are main players. In 2013, Seven Networks announced its plan to collaborate with Intel in order to help operators manage app data traffic and optimize their networks (Hill, 2013). By looking at this collaboration and the titles of top ten patents, we believe that the second community is related to the technology of software-defined networking (SDN).

The third and seventh communities are *inter alia* notable. The third community, which is colored pink, is unambiguously dominated by Google and Nest Labs. It appears that Google has been building up its own knowledge pool, which is recognized by the pattern of self-citations. Self-citation is viewed as reflecting the appropriation of returns (i.e. the more frequently subsequent inventions that occur "in-house", the greater would be the benefits reaped by the original inventor (Trajtenberg et al., 2002)). After the acquisition of Nest Labs in Jan 2014, its second-largest bid ($3.2 billion) (The Economist, 2014), Google has been putting its innovation efforts into programmable thermostats as a controlling device for the system of connected home appliances. A series of self-cited Google and Nest patents (8478447, 8752771, 8757507, 9026254, 9092040, 9104211, 9223323) primarily focus on the development of user-friendly, multi-sensing, self-recharging, and learning thermostats as a control unit for heating ventilation and air-conditioning (HVAC) systems. Similarly, Amazon has been generating its own M2M/IoT technological path in the seventh community, colored light green. The seventh community is composed mainly of Benjamin's patents, including a few of older M2M/IoT patents (7058356, filed in 2001, and 7496328, filed in 2005). Amazon obtained the ownership of subsequent Benjamin's patents (8620208, 8666308, 8718539) and localized the stock of this accumulated knowledge. This set of patents center mainly around interactions between hand-held devices (e.g. mobile phones) and remotely located entities with payment modules (e.g. TV).

Table 3. The assignees of the top 10 patents in the top 10 communities in the M2M/IoT patent citation network

1 🟩 **(26.36%)**	**2** 🟦 **(14.05%)**	**3** 🟥 **(8.46%)**	**4** 🟥 **(7.3%)**	**5** 🟪 **(6.21%)**	**6** 🟦 **(5.95%)**	**7** 🟩 **(5.2%)**	**8** 🟧 **(3.19%)**	**9** ⬛ **(2.95%)**	**10** 🟨 **(1.73%)**
InterDigital (8718688)	Seven Networks (9060032)	Google (9223323)	Mueller Intl (8855569)	Robin Dua (8244179)	iRobot (8265793)	Benjamin Slotznick (7058356)	Nielsen (8930003)	CNH America (8280595)	IBM (7769848)
Symstream (8135362)	Seven Networks (9173128)	Google (9026254)	Magee Scientific (6317639)	Robin Dua (8583044)	DexCom (9028410)	Benjamin Slotznick (7496328)	Qualcomm (8606293)	SynapSense (7995467)	Infineon (8787266)
Apple (8737989)	LG (8811961)	Google (9092040)	Rain Bird (8649907)	Robin Dua (8463184)	iRobot (8892260)	Qualcomm (8831568)	Digimarc (8417793)	Blueforce (8467779)	N/A (8041772)
Ericsson (8407769)	Intel (8619654)	Google (9104211)	Rain Bird (8849461)	Robin Dua (9020429)	Welch (8458149)	Benjamin Slotznick (8131208)	N/A (8094949)	N/A (7917167)	N/A (8498224)
Via Telecom (8737265)	AT&T (9043503)	N/A (8489243)	N/A (6954701)	Robin Dua (8548381)	iRobot (8577501)	N/A (8472935)	ETRI (8116243)	IBM (7822852)	Verizon (8345546)
Samsung (9084074)	HTC (8438278)	Nest Labs (8752771)	N/A (6560543)	Robin Dua (8768256)	DexCom (8844007)	Benjamin Slotznick (7856204)	Digimarc (9084098)	IBM (8898284)	Sprint (8848558)
Qualcomm (9210527)	Intel (8818376)	Nest Labs (8757507)	Sun Micro (7130773)	Robin Dua (8971803)	DexCom (9002390)	Qualcomm (8868038)	Digimarc (8671165)	SkyBitz (8971227)	Sprint (9160629)
Huawei (9107226)	Intel (9130688)	Nest Labs (8478447)	N/A (7424399)	Robin Dua (9160419)	N/A (7639715)	Amazon (8620208)	Nat'l Taiwan Univ (7839764)	Blueforce (8682309)	Sprint (9154976)
Cellco (7774008)	Alcatel Lucent (9208123)	Samsung (8392597)	Harris (8314717)	Robin Dua (9160420)	N/A (7327732)	Amazon (8718539)	Digimarc (8943172)	Blueforce (9066211)	Cubic (8824444)
Alcatel Lucent (9071925)	Huawei (9173244)	Ericsson (9049104)	N/A (7890568)	Robin Dua (9014631)	N/A (6456875)	Amazon (8666308)	Tangoe (9191523)	N/A (8233463)	Cubic (8824445)

Note: In parentheses are the percentage of patents, measuring the size of a community, and patent numbers.

Relying on the concept of "structural holes"(the separation between non-redundant contacts) (Burt, 1992), we identified strategic patents of M2M/IoT, which enabled brokering of the knowledge flow between different patent communities. In Burt's explanations, the lack of ties between different groups generates disparities in information held by the groups, and accordingly a tie that links previously disconnected networks offers strategic benefits of access to non-redundant information. The brokering of a technology introduces new knowledge by different combinations of existing knowledge from disparate communities (Hargadon & Sutton, 1997).

To identify strategic patents, we first extracted patents with high betweenness centrality (up to top 5%). Nodes with high betweenness centrality are of significance since they function as points for control of information flow in the network (Freeman, 1977). Thereafter, we identified strategic patents that link different communities, as shown in Table 4. Considering that the transfer of non-redundant information is more likely to take place along the strategic linkages between different patent clusters, firms which own strategic patents may have control over a source of future M2M/IoT innovation. For instance, Via Telecom's patent 8737265 influences the first community (the largest M2M/IoT cluster) by connecting it with the second community (related to traffic management and network optimization). Qualcomm's patents 8831568 and 8868038 affect the seventh community (connection between M2M devices and mobile communication networks) by connecting it with the first community.

Table 4. Strategic patents of M2M/IoT

Assignee (Number)	Application Year	Title	Connected Communities (In/Out)
Via Telecom (8737265)	2011	Methods and apparatuses for machine type communication	1 <- 2 (In)
LG (8811961)	2011	Method and apparatus for MTC in a wireless communication system	2 -> 1 (Out)
Seven Networks (8438633)	2006	Flexible real-time inbox access	1 -> 2 (Out), 1 <- 2 (In)
Seven Networks (9173128)	2013	Radio-awareness of mobile device for sending server-side control signals using a wireless network optimized transport protocol	2 <- 1 (In)
Seven Networks (9060032)	2012	Selective data compression by a distributed traffic management system to reduce mobile data traffic and signaling traffic	2 -> 1 (Out)
Vodafone (8838806)	2011	Connection management for M2M device in a mobile communication network	1 -> 7 (Out)
Qualcomm (8868038)	2012	Methods of and systems for remotely configuring a wireless device	7 <- 1 (In)
Qualcomm (8831568)	2012	Automatic configuration of a wireless device	7 <- 1 (In)
Magee Scientific (6317639)	1999	Automatic wireless data reporting system and method	4 -> 8 (Out)
Digimarc (8094949)	2000	Music methods and systems	8 <- 4 (In)
Benjamin Slotznick (7058356)	2001	Telephone device with enhanced audio-visual features for interacting with nearby displays and display screens	7 -> 9 (Out)
Iwao Fujisaki (7917167)	2008	Communication device	7 <- 9 (In)

4.2. M2M/IoT trajectory shaped by formal standards (3GPP in particular)

Using the metric of betweenness centrality (top 5%), we visualized the citation network of influential M2M/IoT patents, as shown in Figure 3 (Left). Strategic patents that link different communities are displayed in the figure. This visualization also demonstrates that the first community, colored green, holds a crucial role in the M2M/IoT network. Relying upon Hummon and Dereian's (1989) SPNP calculation method, we identified the top path of the M2M/IoT patent citation network. This method can identify edges with high betweenness centrality. Recently, several researchers relied on this method to find technological trajectories, which represent technological innovations as sequential and interrelated events (Barberá-Tomás, Jiménez-Sáez, & Castelló-Molina, 2011; Fontana et al., 2009; Verspagen, 2007). It assumes that there is a high degree of technology cumulativeness along the trajectories.

The technological trajectory of M2M/IoT, which penetrates the center of the first community, is shown in Figure 3 (Right). Table 5 shows nine patents that center on the M2M/IoT trajectory. Six trajectory patents are also among the top ten patents with high betweenness centrality in the first community, as shown in Table 3. This supports the robustness of this finding. Those six patents are InterDigital (8718688), Apple (8737989), Ericsson (8407769), Qualcomm (9210527), Huawei (9107226),[12] and Alcatel Lucent (9071925).

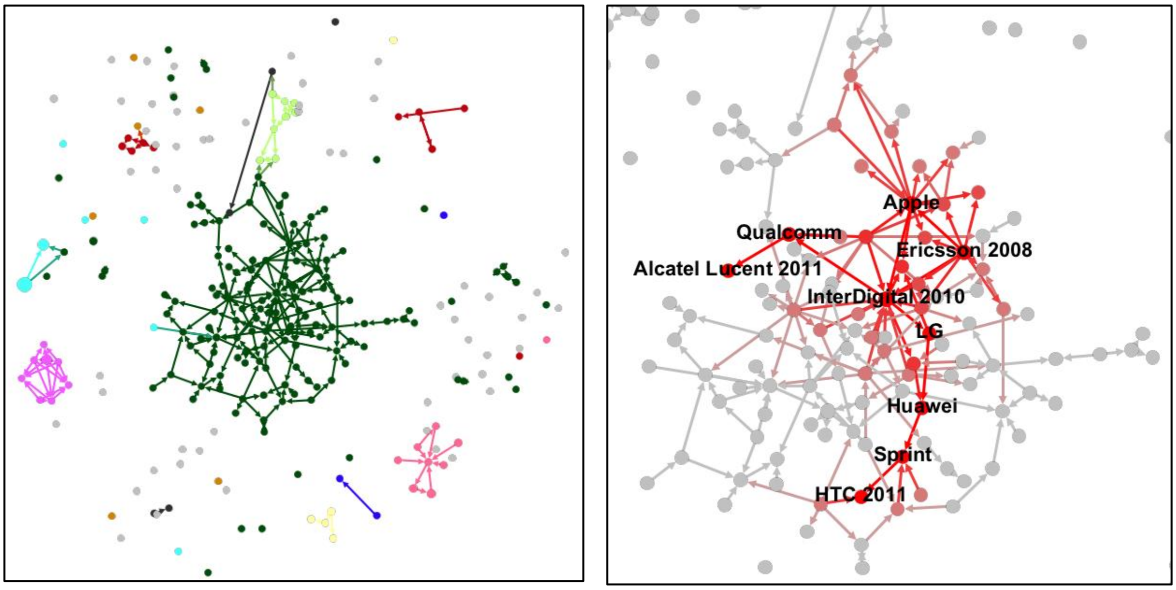

Figure 3. Patents with high betweenness centrality (top 5%) (Left) and M2M/IoT trajectory (Right)

Table 5. Patents that center on the M2M/IoT trajectory

Assignee (Number)	Application Year	Title	Standards
Ericsson (8407769)	2008	Methods and apparatuses for machine type communication	3GPP TR 33.812, 3GPP TS 43.020
Apple (8737989)	2008	Methods and apparatus for machine-to-machine based communication service classes	3GPP TS 23.008, ITU-T Q.763
InterDigital (8718688)	2010	Method and apparatus for solving limited addressing space in machine-to-machine (M2M) environments	3GPP TR 22.868, 3GPP TS 23.003, 3GPP TS 23.060
Qualcomm (9210527)	2011	Method and apparatus for providing uniform machine-to-machine addressing	
Alcatel Lucent (9071925)	2011	System and method for communicating data between an application server and an M2M device	3GPP TS 22.368
HTC (9167470)	2011	Handling signaling congestion and related communication device	3GPP TS 22.368. 3GPP TS 23.107, 3GPP TR 23.888, IEEE Std 802.11
LG (9137624)	2012	Method and device for performing ranging in a wireless communication system	
Huawei (9107226)	2012	Method and system for handling congestion in a communications system	IEEE P802.16b/D2, IEEE P802.16p/D3, IEEE 802.16m-08/004r2
Sprint (8638724)	2012	Machine-to-machine traffic indicator	

Intriguingly, the majority of trajectory patents (6 out of 9) referenced to formal standards, as shown in Table 5. In addition to the M2M/IoT trajectory, the first community is composed primarily of patents that cited formal standards, as shown in Figure 4 (Left). Among the

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[12] The assignee of this patent is Futurewei, which is Huawei's subsidiary located in the US.

patents with high betweenness centrality (top 5%) in the first community, more than half of the patents (83 out of 141) cited formal standards. This demonstrates that formal standards affect the formation of the main cluster and the trajectory in the M2M/IoT patent network. Particularly, 3GPP standards exert a significant influence. Among the formal standards that were cited by M2M/IoT patents, the proportion of 3GPP is dominantly higher than that of other standards, as shown in Figure 4 (Right). Among the high betweenness centrality patents that cited formal standards in the first community, approximately 80% (66 out of 83) of the patents referenced to 3GPP standards.[13] 3GPP TR 22.868, TR 33.812, TS 22.368, TR 23.888, in particular, are referenced by many M2M/IoT patents in the standards-shaped patent cluster. These standards are drafted by 3GPP technical specification group, called Service and System Aspects (SA). This group is responsible for the overall architecture and service capabilities of M2M/IoT systems. This indicates that architectural knowledge embodied in 3GPP SA standards set the boundaries of combinatory explosion in the M2M/IoT technological evolution and guided multiple variations in a certain direction.

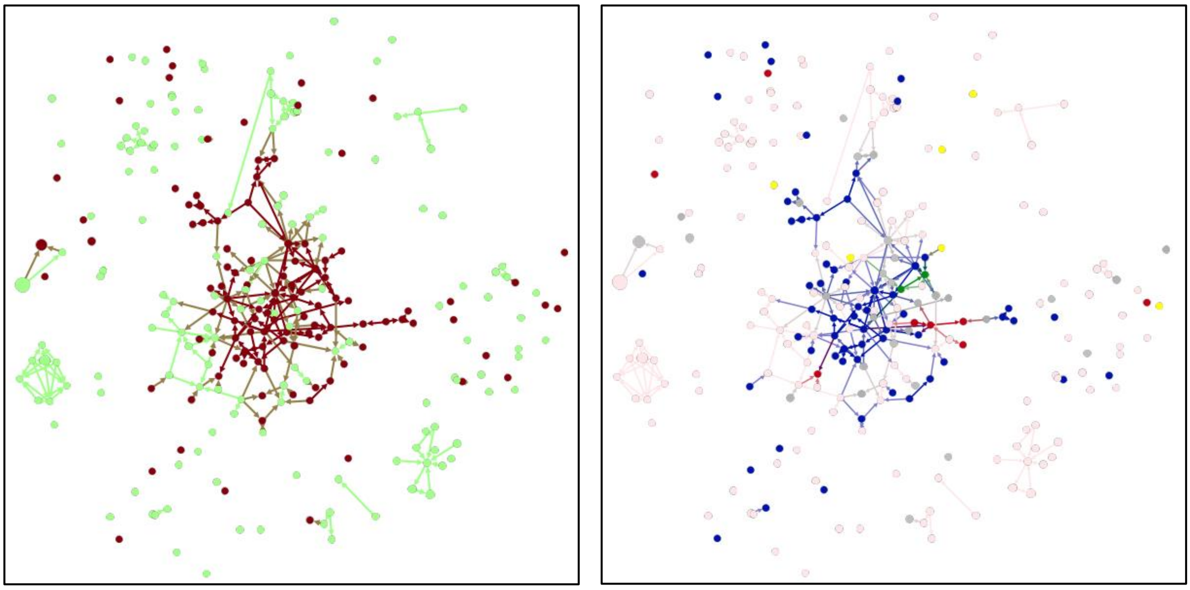

Figure 4. Standards-referencing patents in the citation networks with high betweennness centrality (top 5%). Note: In the left, standards-referencing patents are colored dark red. In the right, patents that reference to different standards are differently colored (3GPP (Blue), IEEE (Red), ETSI (Green), IETF (Yellow), mixed/others (Grey)).

4.3. Technology clusters along the M2M/IoT trajectory

The first community is based on relatively inhomogeneous technologies as compared to other communities, as shown in Figure 2 and Appendix 1. Yet Blondel's et al.' algorithm cannot detect smaller clusters within the first community, as it focuses on the sharing of the same edges. In order to find smaller clusters along the M2M/IoT trajectory which penetrates the center of the first community, patent text similarity and hierarchical agglomerative clustering analysis was undertaken. These methods are of great use to discover the groups

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[13] This number includes patents that cited 3GPP standards together with other formal standards.

of firms with similar technological capabilities. Since firms with similar patents tend to interact in a strategically competitive manner, the finding of those groups helps us to comprehend the dynamics of M2M/IoT innovation. We used the text of granted patents that center on the M2M/IoT trajectory and patents that cited, and were cited by, the M2M/IoT trajectory patents. Duplicate patents were removed. The text of 3GPP standards was also included. To find a change in the M2M/IoT technology clusters, patents were split into two sets: one that represented the earlier M2M/IoT trajectory from 2008 to 2010 (Ericsson (8407769), Apple (8737989), InterDigital (8718688)), and the other that represented the latter from 2010 to 2012 (InterDigital (8718688), Qualcomm (9210527), Alcatel Lucent (9071925), HTC (9167470), LG (9137624), Huawei (9107226), Sprint (8638724)).

For the former set, using Ward's hierarchical agglomerative clustering method, we extracted four clusters around the earlier M2M/IoT trajectory, as shown in Table 6. Ward's hierarchical agglomerative clustering method focuses on node similarity in lieu of the sharing of the same edges. The first cluster contains 55 patents, including two trajectory patents (Ericsson (8407769), InterDigital (8718688)). In the first cluster, as being the largest group, several different firms' technologies are positioned and their share of patents is relatively evenly distributed. Samsung, Qualcomm, Nokia, Jasper and Huawei, *inter alia*, are main industry players, selected by their share of patents within the cluster. This group of firms is in potentially cooperative and competitive relations with respect to M2M/IoT technological innovation. Other three clusters exhibit skewed distributions. Lemko, Ericsson and LG are dominant players in the second, third and fourth clusters, respectively. Lemko is a US-headquartered firm that provides quick deployments of LTE cellular systems with low cost, powered by virtualized and distributed EPC (Evolved Packet Core) and IMS (IP Multimedia Subsystem) solutions (Lemko, 2013). Interestingly in the third cluster, Ericsson and InterDigital have a large portion of patents that are compatible with 3GPP standards.

Using the mean of each cluster's patent similarity, we applied a hierarchical agglomerative clustering method and pairwise comparisons, as shown in Figure 5. At a higher level, the first and fourth clusters, which include the M2M/IoT trajectory patents, are grouped as the same cluster (correlation coefficient = 0.81, p-value < 0.01). The third cluster (3GPP standards) is also similar to the first cluster (main cluster) (correlation coefficient = 0.34, p-value < 0.01). This shows that technologies centering around the main M2M/IoT trajectory are compatible with 3GPP standards. The fourth cluster is statistically significant similar with the first cluster and simultaneously not similar with the third cluster. This finding shows that LG, a dominant player in the fourth cluster, has attempted to create a new technological path that is distinctive with the main M2M/IoT trajectory.

Table 6. Firms which own patents in each cluster around the earlier M2M/IoT trajectory

Cluster 1 (55 patents)	**Cluster 2 (30 patents)**	**Cluster 3 (31 patents and 6 standards)**	**Cluster 4 (32 patents)**
Trajectory: Ericsson (8407769), InterDigital (8718688)		Standards: 3GPP TS 23.003, TS 23.008, TS 23.060, TS 43.020, TR 22.868, TR 33.812	Trajectory: Apple (8737989)
Samsung (12.7%)	Lemko (36.7%)	Ericsson (37.8%)	LG (28.1%)

Qualcomm (7.3%)	Alcatel-Lucent (6.7%)	InterDigital (10.8%)	Apple (9.4%)
Nokia (7.3%)	Motorola (6.7%)	M2M and IoT (5.4%)	Vodafone (6.3%)
Jasper (7.3%)	AT&T (6.7%)	Apple (2.7%)	Intel (6.3%)
Huawei (5.5%)	Ericsson (6.7%)	Alcatel-Lucent (2.7%)	Cellco (6.3%)

Note: Top five firms were selected based on their share of patents in each cluster. Firms' shares are in parentheses.

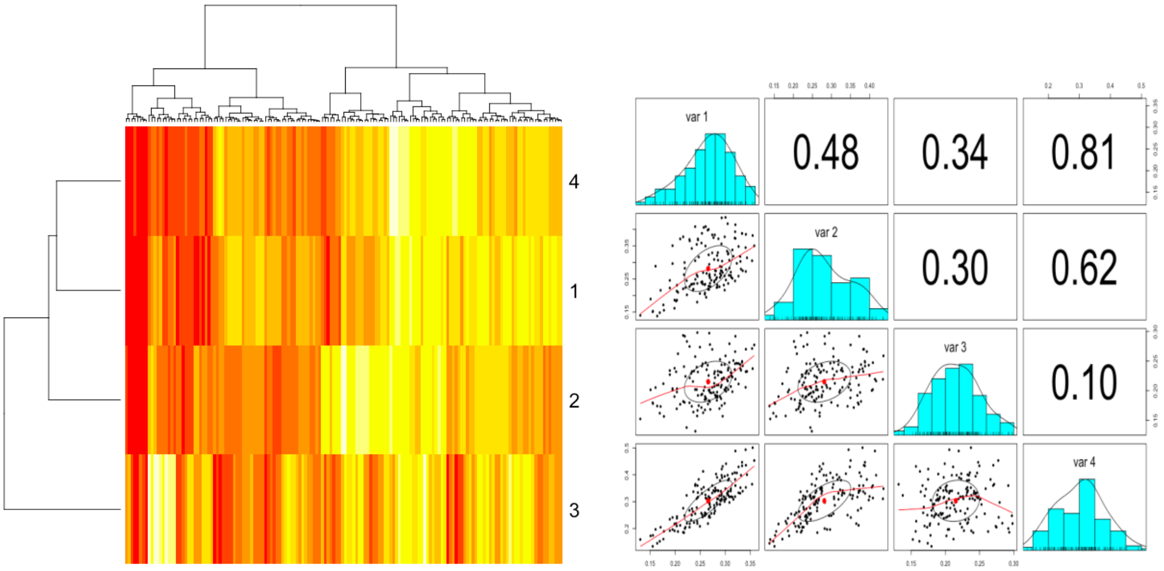

Figure 5. Patent clusters around the earlier M2M/IoT trajectory (Left) and correlations between the clusters (Right). Note: In the heatmap, each row indicates each cluster, while each column indicates each patent. A color closer to yellow represents similarity, whereas a color closer to red represents dissimilarity.

As for the latter M2M/IoT trajectory, we detected four clusters, as shown in Table 7. The first cluster is composed of 46 patents, including five trajectory patents (InterDigital (8718688), LG (9137624), Sprint (8638724), HTC (9167470), Alcatel Lucent (9071925)). This cluster can be regarded the main strategic group in the main cluster of the latter trajectory. Compared to the strategic group positions in the main cluster of the earlier trajectory, the positions of Nokia, LG and Alcatel-Lucent in the main strategic group become more central with the passage of time. InterDigital and Huawei serve as the main players in the second cluster, while Qualcomm holds an influential position in the third cluster. Akin to the earlier trajectory, Ericsson owns a distinctly large portion of patents in the fourth cluster, which are similar with the text of 3GPP standards.

Between-cluster similarities are presented in Figure 6. The similarity of the first cluster with three other clusters is all relatively high. This confirms that the first cluster serves as the main cluster, connecting three other clusters. It is notable that the fourth cluster (3GPP standards) is compatible with the main cluster (correlation coefficient = 0.33, p-value < 0.01), whereas its correlations with other two clusters (second and third) are not statistically significant at the 5% level. It implies that Qualcomm, InterDigital and Huawei have made efforts to generate new technological innovations that are differentiable from the 3GPP standards-based technology.

Table 7. Firms which own patents in each cluster around the latter M2M/IoT trajectory

Cluster 1 (46 patents)	**Cluster 2 (17 patents and 1 standard)**	**Cluster 3 (39 patents)**	**Cluster 4 (10 patents and 5 standards)**
Trajectory: InterDigital (8718688), LG (9137624), Sprint (8638724), HTC (9167470), Alcatel Lucent (9071925)	Trajectory: Huawei (9107226) Standards: 3GPP TS 23.003	Trajectory: Qualcomm (9210527)	Standards: 3GPP TS 23.107, TS 22.367, TS 22.368, TS 23.060, TR 23.888
Nokia (10.9%)	InterDigital (16.7%)	Qualcomm (10.3%)	Ericsson (53.3%)
LG (8.7%)	Huawei (11.1%)	Motorola (7.7%)	Samsung (6.7%)
Alcatel-Lucent (8.7%)	M2M and IoT (11.1%)	Huawei (5.1%)	Alcatel-Lucent (6.7%)
Qualcomm (6.5%)	Fujitsu (5.6%)	Samsung (5.1%)	
Samsung (6.5%)	Ericsson (5.6%)	NTT Docomo (5.1%)	

Note: Top five firms were selected based on their share of patents in each cluster. Firms' shares are in parentheses.

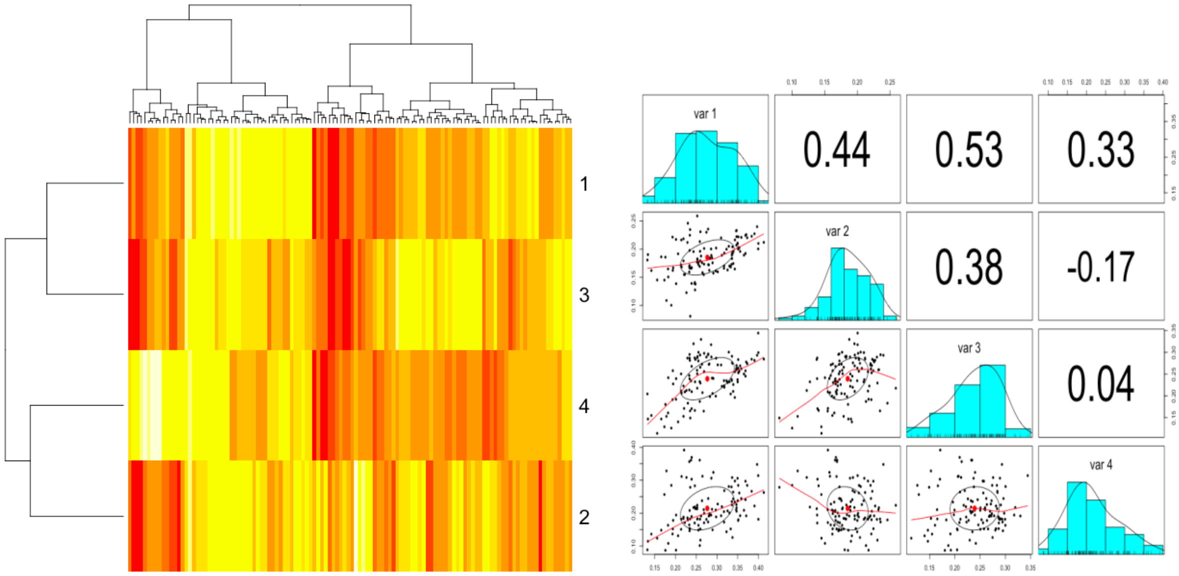

Figure 6. Patent clusters around the latter M2M/IoT trajectory (Left) and correlations between the clusters (Right)

4.4. Hypothesis test results

To empirically examine the effects of formal standards on the basicness of patents, statistical analysis was conducted to test the aforementioned hypotheses (H1, H2, H3). Table 8 shows the test results for H1. In models 1, 2, 3, 4 (Tobit regression), a reference to standards (the main IV) is positively associated with adjusted forward citations (DV) with statistical significance at the 0.01 level. This test result is robust to the violation of the homoscedasticity and normality assumptions, as shown in model 5 (CLAD regression). The robustness of the result is reconfirmed by the negative binomial regression test (model 6). Hence, the first hypothesis (H1) is supported.

Table 8. Empirical test results for the first hypothesis (H1)

	Model 1 (AC)	Model 2 (AC)	Model 3 (AC)	Model 4 (AC)	Model 5 (AC)	Model 6 (FC)
	Tobit	Tobit	Tobit	Tobit	CLAD	Negative Binomial
Standards	0.531**	0.578**	0.574***	0.623***	0.357**	0.367**
Backward citations	0.022***	0.018***	0.017***	0.017***	0.017***	0.006***
Catch-up	-0.258	-0.358	-0.575**	-0.482*	-0.108	-0.420**
Year dummy	No	No	No	Yes	No	Yes
LnFirmSize			-0.099	-0.135	0.010	-0.067
LnIP			0.154	0.167	0.050	0.130*
LnR&D			-0.240*	-0.212	-0.091	-0.184*
Constant	0.258	-0.106	5.022***	5.531***	1.496	6.015***
Observations	421	343	343	343	343	343
Log-likelihood	-664.561	-534.904	-527.890	-525.313		-676.421
Pseudo R^2	0.113	0.043	0.055	0.060	0.082	0.065

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. AC: Adjusted Forward Citations. FC: Forward Citations. Standard errors in parentheses.

Note: Patents that were assigned by small and medium-sized enterprises whose firm-specific information is not publically available were excluded from the analysis in models 2, 3, 4, 5, 6.

Table 9 shows the test results for H2. In model 1 (Tobit), a reference to standards (IV) is negatively associated with the generality of patents with statistical significance at the 0.05 level. A robustness check was also conducted through the CLAD estimator. As shown in models 4 and 5, it validates the test results, supporting the second hypothesis (H2). It is noticeable that the statistical significance of the coefficients on standards drops when we add originality and originality-squared as IVs, as shown in models 2 and 3. This leads us to conjecture the existence of the moderating effect of standards on the association between originality and generality. The test results in models 3 and 5 show that originality and generality are related with statistical significance in a curvilinear manner.

Table 9. Empirical test results for the second hypothesis (H2)

	Model 1 (GE)	Model 2 (GE)	Model 3 (GE)	Model 4 (GE)	Model 5 (GE)
	Tobit	Tobit	Tobit	CLAD	CLAD
Standards	-0.074**	-0.061*	-0.045	-0.085**	-0.068**
Originality		0.225**	-0.678**	0.301**	-0.858*
Originality^2			0.878***		1.094**
Forward citations	0.011***	0.009***	0.009***	0.006*	0.007***

Catch-up	-0.168***	-0.149***	-0.147***	-0.126***	-0.138***
Constant	0.461***	0.308***	0.484***	0.330***	0.575***
Observations	253	253	253	253	253
Log-likelihood	-65.389	-62.159	-58.293		
Pseudo R^2	0.277	0.312	0.355	0.116	0.145

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. GE: Generality. Standard errors in parentheses.

For hypothesis H3, we examined the moderating effect of standards on the relationship between binding force and generality. We added the interaction term between standards and binding force to the test model for generality. The interaction term between standards and originality was also added, since the previous test results (Table 9) indicated the existence of the moderating effect of standards on the association between originality and generality. Forward citations were added as a control variable in the Tobit model in order to tease out the effect of binding force from the build-in coverage effect of a large number of forward citations.

Table 10 shows the moderation test results for H3. The coefficients on the interaction terms between standards and binding force and between standards and originality are statistically significant, supporting H3. A multicollinearity test was also conducted by checking variance influence factors (VIF) (Mason & Perreault, 1991). The test showed that all VIF values were less than 5, indicating that multicollinearity was not likely to distort the test results of this study.

Table 10. Empirical test results for the third hypothesis (H3)

	Model 1 (GE)	Model 2 (GE)	Model 3 (GE)	Model 4 (GE)
	Tobit	Tobit	Tobit	Tobit
Standards	-0.043	-0.470***	-0.031	-0.486***
Originality	-0.603*	-1.758***	-0.484	-1.611***
Originality^2	0.810***	1.907***	0.668**	1.700***
Binding force	0.004	0.006	-0.026*	-0.020
Forward citations	0.008**	0.007**	0.021***	0.018***
Standards × Originality		2.131***		2.010***
Standards × Originality^2		-2.078***		-1.866***
Standards × Binding force			0.069**	0.064**
Standards × Forward citations			-0.017**	-0.014*
Catch-up	-0.148***	-0.142***	-0.152***	-0.143***
Constant	0.466***	0.702***	0.428***	0.683***
Observations	253	253	253	253
Log-likelihood	-58.488	-52.354	-54.750	-49.668

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. GE: Generality. Standard errors in parentheses.

For a categorical moderator, the coefficients on the interaction terms are the differences of the regression coefficients between two subgroups: one without a reference to standards (STD=0) and the other with a reference to standards (STD=1). Subgroup analysis was conducted to examine the moderating effect of standards (Sharma et al., 1981). The graphical representation of the moderating effect of standards is presented in Figure 7.

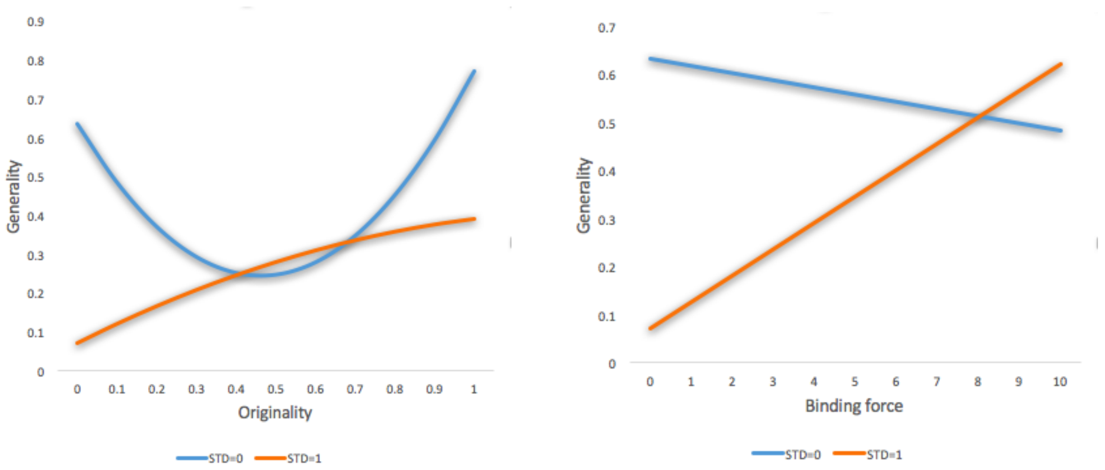

Figure 7. Graphical representation of the moderating effect of standards

Figure 8 shows the results of the pairwise comparisons of the relationships among originality, binding force and generality. In the first subgroup (STD=0), it is shown that there is a curvilinear relationship between originality and generality. There is also a noticeable difference between the two subgroups in the correlation coefficient of the pair of originality and binding force (0.11 for STD=0, -0.11 for STD=1). As compared to the second subgroup (STD=1), the binding force in the first subgroup (STD=0) is pulled by an outlier, as shown in Figure 9. This outlier is Seven Networks's patent 9060032 (selective data compression by a distributed traffic management system to reduce mobile data traffic and signaling traffic), which was regarded as one of the strategic patents of M2M/IoT in Table 4.

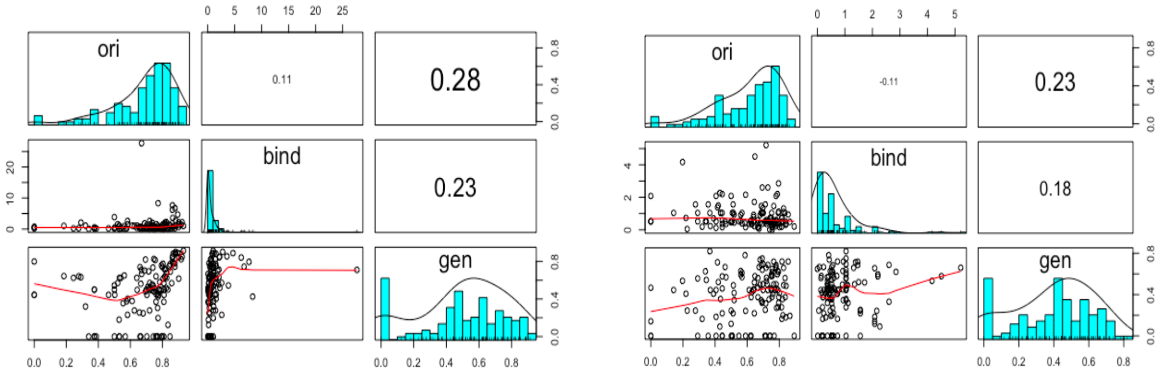

Figure 8. Scatterplots, histograms, correlations for pairwise comparison matrices of originality, binding force and generality. STD=0 (Left) and STD =1 (Right).

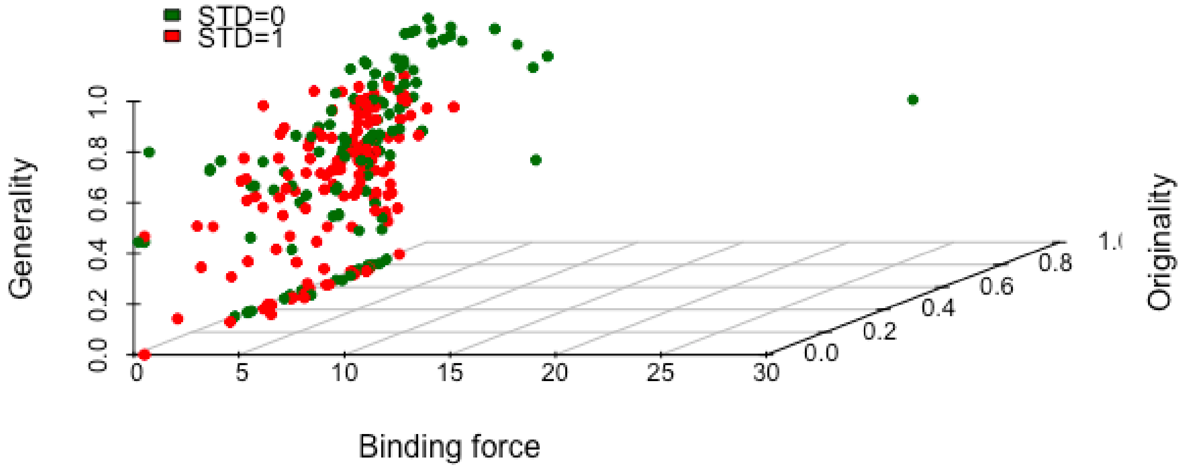

Figure 9. Scatterplot3D of binding force, originality, generality

One more finding is that the patents filed by catch-up firms are less cited by subsequent patents and more specific in the technological field, as compared to firms in other countries (mainly Europe and US), as shown in Table 8 and 9. This is in line with the findings of previous research (e.g. Kang et al., 2014; Park & Lee, 2006) that catch-up firms tend to lack technological resources and capabilities to generate highly valuable technologies and hinge on foreign knowledge, particularly from European and US firms, and thereby selectively focus on a specific technological field. Since the emergence of a new technological paradigm opens a window of opportunity to catch up (Perez & Soete, 1988), latecomer firms, especially from Korea and China, have been vigorously utilizing formal standards of new technologies (ICT in particular) in the catch-up context (K. Lee & Lim, 2001; Yu, 2011). This is confirmed by the independent *t*-test for a difference in means with respect to standards between catch-up firms and the others (mostly European and US firms). Approximately 61% of the catch-up firm group referenced to formal standards, while 44% of the other group cited standards. This difference is statistically significant ($t = 3.298$, $p < 0.01$; equal variances not assumed). Figure 10 shows an increase in catch-up firms' M2M/IoT technologies over time. Catch-up firms tend to rely on formal standards, and thereby their technologies are more concentrated on the center of the patent network.

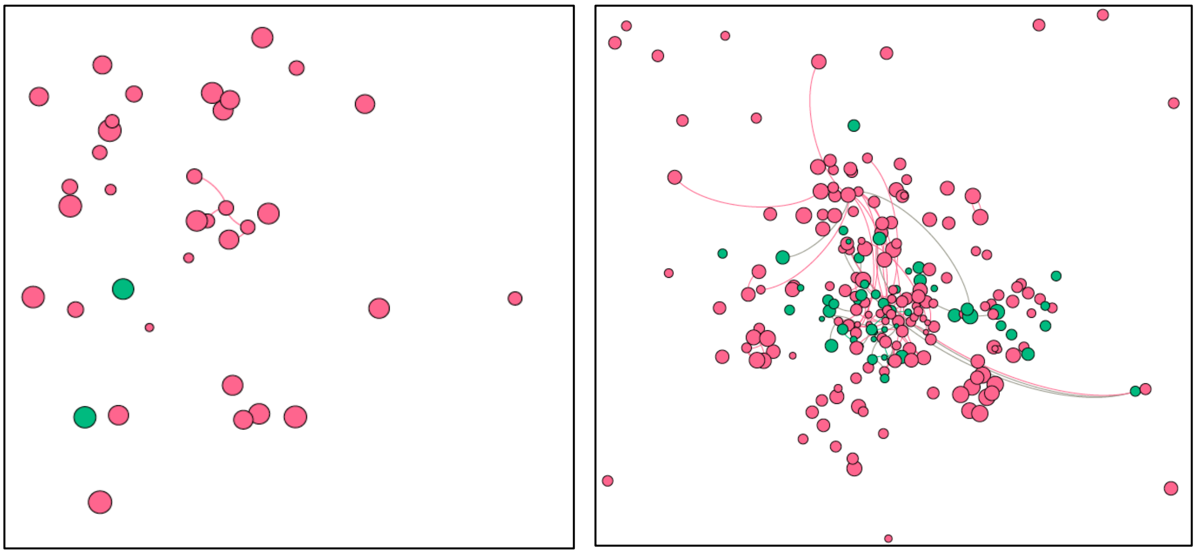

Figure 10. Changes in catch-up firms' M2M/IoT technologies (colored green) in the network of patents with high betweenness centrality (top 5%). Application year 1999-2009 (Left) and 2010-2015 (Right). Node size represents generality.

5. Discussion

5.1. Standards as a driving force of technological convergence

The analysis of the M2M/IoT patent citation network in this paper shows that formal standards affect the clustering of patents with high betweenness centrality and the shaping of a main technological trajectory. This serves as clear evidence demonstrating that formal standards guide the direction of technological change. It is possible because standards constitute the essence of a technological paradigm by which the meanings of technical artifacts and their relational properties are stabilized. This finding is of particular significance in the studies of innovation and standardization since there has been no prior research that identifies a main technological trajectory that has been shaped by formal standards.

According to the results of hypotheses tests, as shown in Tables 8 and 9, technologies based on standards are likely to be more valuable and specific. The confirmation of the first hypothesis is of significance since, to the best of our knowledge, it is the first paper that statistically demonstrates the relationship between a reference to standards and the importance of patents. This accentuates the role of standards as a base for future technological development, particularly in the field of network technologies.

The validation of the second hypothesis that a reference to standards is negatively associated with the generality of patents needs to be carefully read with Cassiman et al.'s (2008) finding that a citation to scientific publications is positively related with the scope of forward citations. Patent citations links to scientific literature have been regarded as an indicator of a highly mediated interaction between science and technology (Meyer, 2000). As a map for technological landscapes, scientific knowledge guides inventors in the direction of new combinatory exploration rather than local search (exploitation) (Fleming & Sorenson, 2004). This explains the positive effect of scientific linkages on the generality of technology (Cassiman et al., 2008). Standards are, by definition, different from scientific knowledge.

Standards attempt to specify an optimized version of technological variants, whereas science focuses on the generalization of research. That is to say, standards' function of variety reduction is key to understand the different effects of science and standards on innovation.

The effects of standards on technological variants are complex since there is the multifaceted and long-range interplay between standardization and innovation (Foster & Heeks, 2013; Zoo, Vries, & Lee, 2017). Standards as dominant designs drive technological progress into the era of incremental innovations (Anderson & Tushman, 1990). This stability continues until the punctuation by a new technological discontinuity that accelerates the rate of technological variation. In ICT standardization, modular designs have been employed to address this inherent tension between stability and flexibility (Hanseth et al., 1996). By setting architectural structures and common interfaces, 3GPP standards enable different subsystems to operate in a compatible manner and offer a foundation for innovations in the long term. This foundational knowledge tends to be frequently cited by subsequent inventions, and gives rise to convergence in complements over time (Greenstein & Khanna, 1997).

The moderating effect of standards on the relationships among binding force, originality and generality, as shown in Table 10 and Figure 7, needs to be factored in the understanding of the impact of standards on technological variations within the context of technological convergence. Discussions on the convergence of computing and telecommunications systems have a long history—for instance, Science Magazine covered David Farber and Paul Baran's article regarding this convergence issue in 1977 (Farber & Baran, 1977).[14] Yoffie (1997) identified three drivers that precipitated these trends: technological factors (semiconductor, software and digital communications), government deregulation and managerial creativity. Technological convergence resulted in industry convergence from vertical integration towards a horizontal structure, which required a high degree of coordination and common interfaces. Despite the significant role of standards in industry convergence and value creation, acknowledged by many researchers (e.g. Jacobides, Knudsen, & Augier, 2006; McGahan, Vadasz, & Yoffie, 1997), previous research has not yet empirically demonstrated the effect of standards as a driving force of technological convergence. The discovery of the moderating effect of standards in this paper fills this research gap.

Prior empirical studies on technological convergence viewed binding forces and technological diversity as crucial factors to investigate convergence across the technological fields (Y. Cho & Kim, 2014; Han & Sohn, 2016). In these studies, high levels of binding forces and technological diversity were deemed as results of technological convergence. Our research added two more factors (i.e. standards and originality) to examine the relationship between binding forces and generality at a technological patent level. According to our empirical test results, the generality of patents without reference to standards is highly dependent on their originality. After passing a certain threshold, patents citing prior art from various fields tend to be cited by subsequent patents from a wide range of fields. Yet binding forces, instead of originality, hold a more significant role in technological diversity for the patents that build upon standards. This means that standards with specific

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[14] Dr. Farber and Mr. Baran were regarded as pioneers who made significant contributions to the development of computer networks (e.g. Packet switched network design and Token Ring).

architectural knowledge and compatibility requirements serve first as a force of concentration that underpins the construction of a large, densely connected community of M2M/IoT technologies. In this community, nodes with high central positions work as a source of attraction that brings relatively heterogeneous technologies.

5.2. Importance of 3GPP standards for M2M/IoT technological evolution

One of the crucial findings in this paper is that 3GPP standards, among formal standards, are most frequently referenced and, in turn, heavily affect the M2M/IoT technological trajectory. Due to high switching costs, investments on a particular standard involve substantial risks, which critically affect the performance of firms in highly competitive technology markets (Cusumano, Mylonadis, & Rosenbloom, 1992; Shapiro & Varian, 1999b). Multiple variants of M2M/IoT standards are currently vying to be selected in the standards-setting committees and become dominant in the market—*iner alia*, 3GPP, ETSI, IETF, IEEE, AllSeen, OIC, Thread, and IIC. Despite the fact that those committees and consortia attempt to differentiate themselves from others in the field of M2M/IoT standardization, some of their standardization efforts overlap and, in turn, come into inexorable competition. In this context, the finding that, among formal standards, 3GPP standards are the one that most strongly shapes the M2M/IoT technological trajectory is particularly relevant for senior managers in the formation of technology strategy.

Standardization efforts within 3GPP have focused upon the optimization of core/access networks for M2M traffic[15] and development of high-level frameworks and service capabilities. Accordingly, 3GPP TR 22.868, TR 33.812, TS 22.368 and TR 23.888 were released in line with those efforts. TR 22.868 (study on facilitating machine to machine communication in 3GPP systems) was first drafted in 2006, identifying potential requirements to facilitate the optimization of radio and networks resources in the followings areas: *inter alia*, handling large numbers of terminals and subscription data, charging, security and addressing. TR 33.812 (feasibility study on security aspects), which became available since 2008, addresses issues regarding remote provisioning and change of subscription for M2M equipment. TS 22.368, first available in 2009, specifies service requirements for M2M communications, which serve as a foundation for architecture and protocol specification in other 3GPP groups. In this standard, a distinction between common-service requirements and M2M features that only apply to a specific subscription is made, predicted upon the idea that telecom operators can differentiate their services on a per-subscription basis (Norp & Landais, 2012). TR 23.888, released in 2009, studies and evaluates the architectural aspects of system improvements for M2M requirements, specified in TS 22.368.

The main flow of knowledge, embodied in the top path of the M2M/IoT patent citation network, reflects a stream of the aforementioned 3GPP standardization efforts. US8407769 (Ericsson, 2008) contains methods that facilitate the automatic linking of a newly activated M2M devices to an appropriate server for downloading subscription credentials. US8737989 (Apple, 2008) includes methods to enable a wireless network to identify

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[15] There are differences between M2M traffic and H2H (human-to-human) traffic: 1) synchronized; 2) unpredictable; 3) bursty; and 4) uncontrollable. For details, see Benrachi-Maassam (2012).

subscriptions and then offer differentiated services to a M2M client based on this identification. US8718688 (InterDigital, 2010) provides methods for solving limited addressing space in M2M environments where communications between a controller and a group of transmit/receive units, having a same international mobile subscriber identity (IMSI), take place. It is noticeable that the M2M/IoT technological trajectory in line with 3GPP standardization efforts has been taking shape in response to well-recognized needs in the market (i.e. a smart, connected product as a service (Porter & Heppelmann, 2014)). The product-as-a-service model can be maintained through the provision of differentiated services on the basis of their subscription data. This flow of discussion leads to another finding that the direction of a path-dependent technological trajectory is influenced by market demand-embodied formal standards.

5.3. Two different types of technology clusters (standards-based and platforms-based clusters)

The discovery of technology clusters in the M2M/IoT patent network shows the groups of firms with similar M2M/IoT technological capabilities. This finding is of significance especially during the era of M2M/IoT-driven industry convergence where the boundaries of traditional industrial sectors become blurred and, in turn, convergences in complements (use in concert) and in substitutes (interchangeability) become growingly important (Greenstein & Khanna, 1997). Bound to a common fate in the face of uncertainty, firms with similar technological capabilities in the strategic groups are likely to create different "strategic blocks" and compete with one another (complementary blocks composed of firms from different strategic groups and pooling blocks composed of firms from the same strategic group) (Nohria & Garcia-Pont, 1991). This group-based competition is critical in value creation and battles over technological standards (Gomes-Casseres, 1994; McGahan et al., 1997).

Those firms with similar M2M/IoT patents are likely to interact in a cooperative and competitive (coopetitive) manner in their value networks. Cooperation takes place among complementors in order to create value (a larger pie), whereas competition occurs in a way to appropriate value (a larger slice) (Brandenburger & Nalebuff, 1996). In the face of technological challenges and opportunities (e.g. the setting of technological standards), giant firms actively engage in coopetition, which results in subsequent coopetition among other firms and the advance of innovation (Gnyawali & Park, 2011). In the formation of strategic linkages, firms' resources (e.g. accumulated technological assets and radical technological breakthroughs) and their network positions (crowding and prestige) exert a gravitational pull (Ahuja, 2000; Stuart, 1998). Firms in the central position (in terms of betweenness) of a concentrated interfirm network (in terms of density) are more likely to successfully develop explorative innovations (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008).

In our analysis of patent text similarity (Tables 6 and 7), Ericsson, InterDigital, Samsung, Qualcomm, Nokia, Jasper, Huawei, LG, and Alcatel-Lucent are main firms in the same strategic group composed of similar technological capabilities that are compatible with 3GPP standards. Those firms are likely to intensely interact in a cooperative and competitive manner in order to create and appropriate value in the face of M2M/IoT standards-driven convergence. Standards-based alliances have been strategic responses to the growing complexity of ICT-driven technological systems (Rice & Galvin, 2006). The texts of Ericsson's patents are most similar to those of 3GPP standards. Interestingly, InterDigital, Huawei, and Qualcomm created different technology clusters that were less similar to 3GPP standards along the M2M/IoT trajectory over time. It implies that those firms attempted to diversify 3GPP standards-based M2M/IoT technologies, generating new paths of the M2M/IoT trajectory.

As shown in the M2M/IoT technological communities (Table 3), Google and Amazon carved out their self-reliant technological trajectory through acquisition of strategically important patents, instead of relying on formal standards. This market-oriented approach can be regarded as part of "platform envelopment", which refers to an entry into adjacent markets by bundling their own platform's functionality with that of other products and services, leveraging common components and overlapping user bases (Eisenmann, Parker, & Alstyne, 2011). Envelopment opportunities for platform leaders arise with a large-scale industry convergence which allows them to compete in a multi-layered technological space with different platforms (Eisenmann, Parker, & Alstyne, 2006). Platform leaders often use envelopment as a "tipping" strategy to build market momentum and win a platform competition (Gawer & Cusumano, 2008).

Google has made inroads into many different markets by connecting new technological features to its search platform, innovatively linked with an ad-based business model (Kenney & Pon, 2011). In January 2014, Google acquired Nest's learning thermostat and absorbed technological knowledge regarding a control unit in the network of home appliances (The Economist, 2014). By combining new technological features building upon this stock of knowledge with existing platforms and services, Google attempted to create its own IoT ecosystem where cross-platform interoperability was ensured to reduce the costs of multi-homing (i.e. affiliating with multiple platforms (Eisenmann et al., 2006)). In turn, users were able to enjoy a plethora of platform-agnostic services, whereas still locked in Google's search engine (i.e. the core of the Google ecosystem, funneling user data into its database to produce, accumulate, and re-appropriate value (Pasquinelli, 2009)). The accumulated experience of a user interface affects the way switching costs results in user resistance to change, and thereby works as a critical factor in multi-platform competition (D. Kim & Lee, 2016). In this context, the creation of a user-friendly interface for control unit is crucial for Google's tipping strategy, as shown in its patent 9223323.

Likewise, Amazon has been trying to offer various web services on top of its own platform where all the transaction data of users is stored in its database to capture value. Its efforts to obtain Benjamin's M2M/IoT patents can be interpreted within the context of an envelopment attempt to connect household gadgets to Amazon's existing functionality and services, building on its e-commerce platform and cloud infrastructure. A platform owner emphasizes the role of a gatekeeper which allows the firm to exercise control over its platform and, in turn, focuses on the development of gatekeeper functions, such as profile/identity management, service provisioning/service brokerage, and charging and billing (Ballon, 2009). The control of customer identity information that can be charged for viewing contents is critical for Amazon's gatekeeper strategy, as shown in its patent 8666308.

There is a noticeable pattern in the different technology clusters of the M2M/IoT patent network. Previous research identified changes in industry structure in the face of technological convergence as a horizontal structure (chips, computer, operating system, application software and distribution in the computer industry (Grove, 1996) and terminals, manipulation, transmission, packaging and content in the converging industry of telecommunications, computing and entertainment (Collis, Bane, & Bradley, 1997)). According to our analysis, firms previously involved in terminal and transmission sectors tended to develop similar technological capabilities, which were compatible with formal standards (e.g. Samsung, Apple, LG, Huawei, Ericsson, and Nokia). Firms in manipulation and packaging sectors honed in on self-reliant technologies that were essential for their platform envelopment and gatekeeping roles (e.g. Google and Amazon).

5.4. Standards for a path-creating catch-up and Huawei's rise

Our findings confirm that the M2M/IoT technologies of catch-up firms are more concentrated on a standards-based cluster, as shown in Figure 10. It appears that catch-up firms play a growingly important role in the creation of a new path along the M2M/IoT trajectory. It is particularly noticeable that Huawei initiated a path-creating catch-up. The finding of patent text similarity (Table 7) shows that Qualcomm, InterDigital and Huawei actively engaged in technological diversification, distinguishable from other 3GPP standards-based technologies. Previously, the knowledge positions of Qualcomm and InterDigital only were considered strong in standards-based markets (Bekkers & Martinelli, 2012). In our analysis, Huawei's role in the shaping of the M2M/IoT trajectory is growingly influential. For instance, Huawei's patent 9107226 (congestion handing in a communication system) referenced to the IEEE 802.16 standard (WiMax). This patent is cited by HTC's patent 9167470 (signaling congestion handling), which referenced to 3GPP standards. This path of connecting two different standards-based technologies serves as an important part of the M2M/IoT trajectory. This finding stresses the significance of standards as a post catch-up strategy.

In the analysis of our dataset, over 70% of Huawei's M2M/IoT patents referenced to 3GPP standards, especially TR 22.868, TR 33.812, TS 22.368 and TR 23.888. By contrast, ZTE, another Chinese catch-up firm, has relied relatively less on formal standards. Only 35% of ZTE's M2M/IoT patents cited to 3GPP standards-related documents, some of which were just 3GPP working group papers. This shows that Huawei has been making innovative efforts, more squarely related to the 3GPP-shaped M2M/IoT technological trajectory, in comparison to ZTE. This implies that Huawei already recognized the strategic importance of 3GPP standards with respect to an emerging M2M/IoT technology and, in turn, vigorously built their technological capabilities in line with these standards.

6. Conclusion

With a growing strategic importance of understanding the M2M/IoT trajectory and its relationship with formal standards, this research offers several findings and theoretical/practical implications. First, our empirical analysis shows that standards serve as a driver of technological convergence. Second, we found that 3GPP standards regarding the overall M2M/IoT system architecture (TR 22.868, TR 33.812, TS 22.368, and TR 23.888, in particular) assume a leading role in the shaping of the M2M/IoT trajectory. Third, we identified strategic groups and strategic patents centering around the M2M/IoT trajectory. This identification is crucial to understand the dynamics of strategic competition in the

M2M/IoT standards-driven converging world of Internet and things. Forth, standards serve as a critical factor in the process of creating a new path for catch-up firms (e.g. Huawei).

There findings are expected to provide contributions to innovation and standards studies by empirically investigating the relationship between technological trajectories and standards. Yet these findings should be interpreted with care. There is a possibility that a reference to 3GPP standards is the most decisive factor for US patent examiners to categorize M2M/IoT patents into CPC code H04W/005, which may result in a bias in the finding of 3GPP standards' significant impacts on the M2M/IoT trajectory. Despite the fact that we cannot completely rule out this possibility, the existence of the non-H04W/005 patents citing those 3GPP standards and the H04W/005 patents not citing the 3GPP standards indicates that the probability of this factor causing a bias in the finding is not great. For future research, it would be relevant to further investigate the dynamics of strategic competition in the standardization process of M2M/IoT-related 3GPP standards.

There are some limits on this research. First, we relied on several different algorithms to detect technology clusters in the M2M/IoT networks, including non-deterministic, approximation methods (e.g. Blondel's et al.'s modularity optimization). Non-deterministic approach hinges on initial conditions and/or parameters of the algorithm, and thus may not deliver an exactly same solution to the same problem. In order to overcome this weakness, we attempted to use different methods to check the robustness of our findings. For instance, the CW algorithm was used to support the technology clusters in the M2M/IoT network, identified by Blondel's et al.'s algorithm. Node betweeneess centrality was also employed to confirm the central positions of trajectory patents in the M2M/IoT network. Second, there are insufficient explanations on the characteristics of each cluster in the M2M/IoT network, despite some explanations in the paper—for example, these technology clusters emerged based on the sharing of similar information (e.g. 3GPP standards) or the group of firms with strategic interest (e.g. Google and Nest Labs). This leaves open room for future research on the emergence of different technology clusters in the M2M/IoT network.

Acknowledgement

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A3A2043505) and ICONS (Institute of Convergence Science), Yonsei University.

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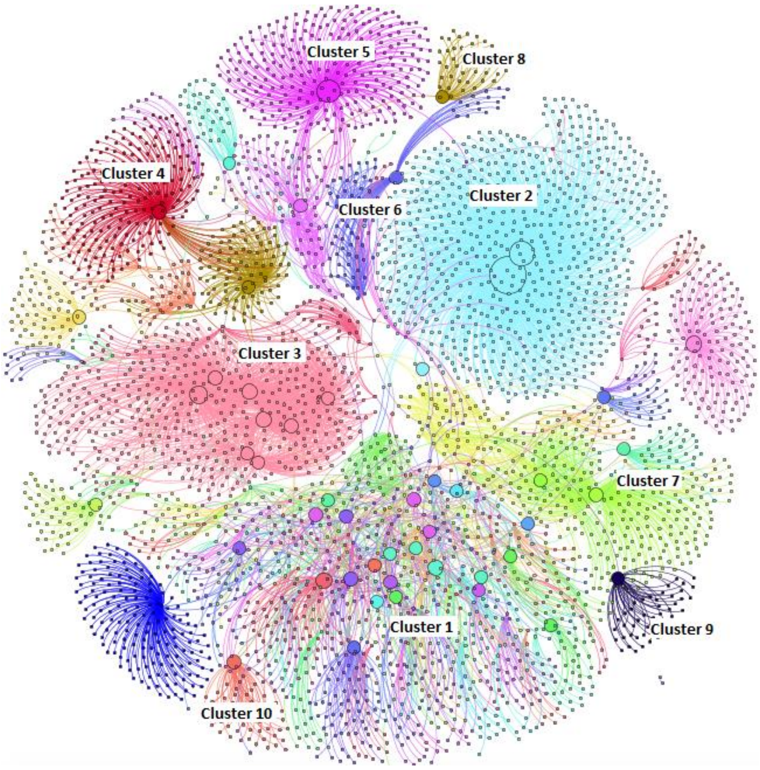
Appendix

1. Clusters in the M2M/IoT patent citation network, identified by the Chinese Whispers algorithm



Clusters 1–10 similarly matches communities 1–10, detected by Blondel et al.'s modularity optimization method, as shown in Figure 2. The size of nodes is measured based on betweenness centrality.

2. Glossary

3GPP	3rd generation partnership project
CLAD	Censored least absolute deviations
CPC	Cooperative patent classification
ETSI	European telecommunications standards institute
GSM	Global system for mobile communication
IEEE	Institute of electrical and electronics engineers
IETF	Internet engineering task force
IIC	Industrial internet consortium
IPC	International patent classification
IoT	Internet of things
LSA	Latent semantic analysis
M2M	Machine-to-machine
MTC	Machine-type communications
NPL	Non-patent literature
OIC	Open interconnect consortium
RFID	Radio-frequency identification
SCADA	Supervisory control and data acquisition
SSO	Standards-setting organization

STD	Standards
TR	Technical report
TS	Technical specification
UMTS	Universal mobile telecommunications service
VIF	Variance influence factors
WCDMA	Wideband code division multiple access
WSN	Wireless sensor network
WiMax	Worldwide interoperability for microwave access