Role of formal standards in transition to the technology frontier: Korean ICT systems

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ABSTRACT

According to traditional wisdom, latecomer countries improve their technological capabilities in reverse of the product cycle, that is from mature towards new technologies. However, improvement of standards capabilities in this process has not been revealed clearly. This paper confirms similar patterns for improving formal standards capabilities as for the technological capabilities, but records some possible differences in the rate of catch-up when latecomers approach the technology frontier; a forward moving position where technology leaders (typically advanced countries) develop or conceptualize new technologies before being turned into products or systems. A number of case studies of South Korean ICT systems reveal that transition to the technological frontier is increasingly related to how they target and carry out formal standardization. The common elements driving differences in rates of successful catch-up for ICT systems standards are not only limited to generic standards capabilities, but also rely on characteristics of technology trajectories, national strategic focus, and organizing for standardization.3 This implies that a nation should not be discouraged by slow progress in standards-setting during earlier stages. Once a minimum level of capabilities is achieved, a nation pro-active in standards from the beginning may attain higher rates of catch-up near the technology frontier.

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1. Introduction

Over the last decades, the South Korean innovation system has managed to upgrade its innovation capabilities from capital-intensive products to complex telecommunications and broadcasting systems at the technological frontier (Choung, Hwang, & Yang, 2006; Mani, 2005; Mytelka, 1999). The indigenous development of digital switches for public switched telephone networks and world-first commercialization of CDMA wireless networks has been rapidly extended to the development of new homegrown standards-based systems like Wireless Broadband (WiBro), Terrestrial Digital Multimedia Broadcasting (T-DMB), and part of the Transport Protocol Expert Group (TPEG). Moreover, Korea’s contribution to International Standards Development Organizations (ISDOs) has become quite significant for the 4G wireless technologies,
Next Generation Networks (NGNs), and Internet Protocol Television (IPTV) standards. It is intriguing how Korea could achieve such performance in formal standards\(^4\) in such a short period of time, and how can that be explained in relation with the rate and direction of its technological catch-up.\(^5\)

Kim (1980, 1997) provided a comprehensive explanation of Korean technological development mainly in the electronics sector. He demonstrated that patterns of accumulating technological capabilities advance through three stages i.e. in reverse of the original product cycle proposed by Utterback and Abernathy (1975). In the first stage, Korea imported and learnt to use mature technologies from foreign partners, and during the second stage, it was able to make its own improvements mostly in process and production technologies. Finally, in the last stage (near the global technology frontier) Korean firms could create entirely new innovations ahead of competitors. This pattern is commonly known as the Reverse Product Cycle (RPC) of technological catch-up, which has been confirmed for many East Asian Newly Industrialized Economies (NIEs) (Hobday, 1995; Lall, 1997).

However, the literature has not elaborated on the characteristics, patterns, and role of catch-up in standards with respect to technological catch-up. Recently, International Telecommunications Union (ITU, 2007) reported a “standardization gap” in production and control of ICT standards between developed and developing countries, which implies different levels of global standards-setting capabilities. This necessitates understanding of actual patterns of closing such gaps, if any, rather than mere identification of ex-ante roadmaps. Standards as a means of knowledge acquisition and dissemination is different from traditional mechanisms like technology transfer agreements and licensing; therefore, they necessitate additional capabilities suitable to coordinate their development and effective implementation. Standards capabilities are different and additional to technological capabilities, for example legal, political, and language capabilities (Ratanawaraha, 2006). Therefore, a detailed description of successful Korean catch-up in proposing its own standards may reveal why and how latecomers should address catch-up in standards along with their technological catch-up. It can potentially show if a conscious and pro-active approach to standards capabilities may lead to larger benefits of technological catch-up or otherwise. Thus, main intention of this paper is to explore and suggest the patterns and role of ICT standards capabilities in technological catch-up at national level, especially near to technological frontier.

This paper is arranged in six sections. Some key literature on standards and standardization in latecomer countries is introduced in Section 2. In Section 3, the analytical basis are set up and the elements characterizing the accumulation of standards capabilities in relation with technological catch-up are identified. The research methods and data sources are also described. In order to test the claims, multiple case studies about systems and formal standards developed by Korea over the last two decades are discussed in Section 4. These case studies include: (1) Telecommunications Systems and Networks, (2) Data Communications and Internet Systems, (3) Digital Media Broadcasting Systems, and (4) Next Generation Networks. Section 5 provides an analysis of the case studies. Finally, Section 6 concludes and provides implications for technology and standards policy of second-tier catching up countries.

2. Literature review

2.1. Technological catch-up in latecomer countries

The recent industrialization and technological development of the Asian Tigers was based on high rates of accumulation and upgradation of their technological capabilities (Lall, 1997). Some key studies on closure of gaps with forerunners identify the stages and processes of accumulating technology capabilities from imitation to innovation (Kim, 1980, 1997; Lee, Bae, & Choi, 1988). Using the three stages of dynamics of innovation and their characteristics proposed by Utterback and Abernathy (1975) in the product cycle model, Kim (1997) has demonstrated that latecomers catch-up with front runners in the reverse order. Initially, they have little choice but to acquire and imitate foreign technologies during maturity phase of product cycle, where process innovation is driven by costs. The next phase is when technologies are just taking off, where latecomers can improve foreign technologies to some extent (mainly process and production) before maturity. As fast followers, sometimes they can innovate and enhance the productivity more than the forerunners, though such innovation is not entirely original. Once their technological capabilities are raised further, the latecomers are able to bring out their own creative innovations in the third (fluid) phase near to technological frontier. Similar patterns, namely Original Equipment Manufacturing, Original Design Manufacturing, and Original Brand Manufacturing (OEM–ODM–OBM) have been demonstrated in electronics manufacturing by South East Asian economies (Hobday, 1995). Some examples also signify stage-skipping or path-creating catch-up in Korea (Lee & Lim, 2001).

The technological catch-up of East Asian latecomers has commonly benefited from institutional intervention and government control (especially in Korea and Taiwan), for example Amsden (2001), Choung, Hwang, Choi, and Rim (2000).

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\(^4\) A formal standard is developed through a formal standards-setting process at a Standards Development Organization (SDO), expert consortium (e.g. IEEE or MPEG) or industrial consortium (e.g. MIPI). Further classification with reference to the standards-setting process, e.g., de jure and de facto is a bit fuzzy. For example, a standard developed by a firm may become a ‘de facto’ standard following a standards battle in the market. ‘De jure’ merely refers to the mandatory or voluntary implementation of any standard.

\(^5\) Technological catch-up generally refers to the closure of gaps between nations (or firms) to innovate new technologies, products or processes. The technological capabilities are represented by a number of direct or proxy measures, for example, number of patents granted, indexed publications, etc. and other monetary outputs with reference to specific technologies.
and Vogel (1991). Even so, different industry structures and their dynamics hint at differences in sectoral and national policies, for instance, Korean development relied on giant 'Chaebols' (large industrial groups) but Taiwanes development largely came from Small and Medium Enterprises (SMEs) (Choung, 1998). The increasing levels of education and human resources mobility are other factors leading to fast catch-up. The key processes of learning in the first two stages of catch-up were identified as acquisition, assimilation, and improvement of knowledge (Kim, 1997; Lee et al., 1988).

However, latecomers face newer challenges and dilemmas for transition to leadership (Dutrenit, 2004; Hobday, Rush & Bessant, 2004), of which a major one is managing standards for strategic advantage. Standards, as a means of advanced knowledge dissemination and sharing, is different from typically closed mechanisms during catch-up, for example technology transfer contracts, licensing, joint ventures, and R&D alliances. Therefore, they limit the options as well as require additional capabilities of identification and coordination for safeguarding own technological, political, economic, and social interests (Choung, Ji, & Hameed, 2010; Ratanawaraha, 2006).

Whereas literature on standards and standardization has increased in general, studies about technological catch-up paid less attention to accumulation of formal standards capabilities by latecomers. The changing role of standards and details on standards capabilities for search, selection, development, and implementation of standards has not been elucidated. The process and organization for setting standards has been discussed in some cases, but ignoring the dynamics of catch-up in the long run generally. The deficiency stems from many facts. At first, there are not many latecomers successful in developing and proposing their own formal standards (ITU, 2007) at the international level, except Korea and to some extent China (Lee & Oh, 2006, 2008; Lee, 2006). Second, catch-up literature has typically targeted mature capital-intensive technologies, which emphasize on production and quality standards. In contrast, formal standards also focus on evolution of technology and reduction of risks prior to competition in the market. Therefore, they have an essential role in early stage of the product cycle which is actually the last stage of catch-up near the technology frontier. Lastly, ICT standards and standardization has grown phenomenally over the past two decades with a plethora of Standards Development Organizations (SDOs) for formal and de facto standards being setup. Therefore evidence on standards capabilities and successful catch-up may not have been available or meaningful previously.

2.2. Catch-up in ICT standards and standardization by latecomer countries

Many high level studies by ISDOs and their experts show that latecomer developing countries are restrained in proposing own global standards due to the limitations of resources and commitment to access and learn them (Henson, Preibisch, & Masakure, 2001; ITU, 2007). This implies need for gradual improvements in access and related resources by participating in international standards-setting. Some argue for strengthening particular institutions or political systems as the key to success in standards (Drahos, 2002; Stephenson, 1997). This is because they show the influence of political and institutional factors on the standards process arising from stakeholders' interests in guiding technological trajectories and defining new markets.

As standards are manifestations of technology, it is obvious that learning about standards relies on the need to learn technologies. This means standards capabilities have to be gained in parallel or shortly after the technological capabilities are acquired. For instance, adopting of standards developed by foreign nations should come first, followed by improving those, and finally developing and proposing own standards. Only a few studies have specifically targeted catch-up in standards and standards capabilities (for example, Ratanawaraha, 2006; UNIDO, 2005).

Ratanawaraha (2006) used cases of semiconductor and mobile communication products in Korean firms to discuss Late Standardization, i.e. standards capability buildup by latecomers in line with the RPC (Kim, 1997). He proposed acquisition, maintenance, and adjustment of standards as the primary activities in the first two stages of catch-up, whereas learning, linking, and leveraging resources are primary activities to enhance the speed of catch-up across multiple standards. Furthermore, he demonstrates adoption of standards for quality, productivity, and process management initially, followed by engagement in the international and domestic standards-setting for the same standards, comparatively in the earlier stages of technology development. Finally, if the latecomer can sustain and improve the rate of catch-up, it can move onto creation of own standards (Fig 1). Ratanawaraha (2006) identified a number of generic standards activities and capabilities for each stage, for example those pertaining to legal, language, and coordination. However, his study focused on standards for manufacturing processes at firm level, which are different from system-level anticipatory standards and face difficulty to be considered as formal standards. It is evident in his model that firms ultimately target de facto standards capabilities for which they have to learn formal standardization first. Moreover, the implications for standards capacity at the national

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6 Standards can be classified from the perspectives of actors involved, organizations responsible, process of setting standards, business models, extent of obligation, etc., each with possible further sub-classifications. Chapter 1 in Jakobs (2006) provides a critical discussion on existing definitions, ambiguities, and further directions to objectively define and use the terms of standards and standardization, particularly IT. The use of terms formal, de facto, de jure, and anticipatory standards in this paper follow the above source.

7 Standardization can be seen as managing the processes of search, selection, discussion, and writing, revision, replacement or disposal of standards. These processes are spread throughout the invention, innovation, and diffusion phases of a technology (Cargill, 1995; Mansell & Hawkins, 1992). Söderström (2004) classified these processes into three broad phases, namely Planning, Execution, and Implementation. The former two occur early in the product cycle before competition begins in the market, whereas the implementation includes both regulation/approval of a formal standard making it a de jure standard, or otherwise compete for diffusion, or both in case of multiple de jure standards.
level cannot be fully supported by firm level studies. Formal standards for systems are established at ISDOs, many a times to manage the evolution of technologies by establishing architecture and interfaces early in the product cycle, hence called anticipatory standards. Even, these standards will have to compete for market diffusion like all other standards do, except the ones enforced or regulated i.e. de jure.

**UNIDO (2005)** compared two scenarios of advanced standards-setting nations and their followers highlighting the challenges, opportunities, and implications for managing competitiveness through their standards policy. They found the impact of standards on long-term technical change is somewhat similar in both cases, differing in intensity rather than direction. The use and introduction of quality and safety standards during earlier stages can narrow productivity and quality gaps in developing countries more significantly, while information standards play an important role throughout the catch-up. Clearly, that implies developing countries have to follow technological trajectories set by forerunners, that is, standards usage towards generation or from standard-takers to standard-makers. However, a limitation is its neglect of sectoral differences, for example, network effects and externalities pervasive in ICTs.

Neither of the above approaches, at the firm level and the policy level, is helpful in explaining what may be significant for long term national catch-up in ICT standards-setting other than generic standards activities. Unlike mass-manufactured products, systems are composed of many sub-systems and product-elements manufactured by many players. ICT systems rely heavily on standards for interfaces, so agreement on compatibility and interoperability between major actors is essential (Grøtnes, 2008; Sherif, 2001; Vries, 2006) prior to market competition and diffusion. Although, the formal standards-setting at consortia is increasing (Hawkins, 1999), it may not fit well with the logic of dominant design.

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**Fig. 1.** Linking the dynamics of innovation in developed countries with technological catch-up and standards catch-up by latecomers. 
*Source: Adapted from Ratanawaraha (2006).*
That implies there may not be a single order of learning a specific type of standards process and/or capabilities for systems level standards.

In addition, clarification is also necessary for the assumption of previous studies that capability to develop standards is a necessary condition to make a transition from fast follower to technology leadership (Ratanawaraha, 2006). Otherwise, a firm (from a specific nation) can remain trapped in fast-followership of systems standards, although it may become a market leader in certain product standards. Moreover, one firm can seldom have expertise and control in all technological domains of a system product. Therefore, buildup of technological and standards capabilities for complex systems cannot be best viewed at the firm level but only at the sectoral or national level. Many times, the search and selection of future systems technologies takes place outside the boundary of the firm. Furthermore, a firm weighs its assets and capabilities differently than an innovation system, which may impact the available strategic choices to each.

In sum, the literature provides sufficient insights on generic catch-up in standards but leaves some gaps in understanding of national level standardization for formal ICT standards and their roles in catching up by latecomers, especially near the technology frontier.

3. Analytical framework

The above discussion reveals that catch-up in standards is somewhat similar to stage-based RPC patterns for technological catch-up. However, factors like technology trajectories, the formal standards process, and the level of analysis (firm or national level) may also affect the dynamics of catch-up in standards, given that inner details are considered. There may be no or little differences in the overall direction; nonetheless, differences in the rates of catch-up imply a strategic nature of the factors themselves. Therefore, patterns of catching up need to be confirmed for formal ICT standards at the national level.

It is not difficult to judge that relationships and links built with ISDOs for a particular standard development will not end with the obsolescence of the technology or standard. In fact, the same links can be used again for other technologies with less effort, if compared to a new alliance or project for technology development at the firm level. Given the peculiarities of ICT systems discussed at the end of the last section, it is reasonable to say that once a national system has gained a minimum level of standards capabilities, it may be possible to skip some processes to increase the rates of catch-up. That may lead to differences in rates of catch-up which may be traced by looking at the entry point of particular standards, i.e., where did they initiate and how did they proceed into product cycle and the standards processes within.

The analytical framework is based on the above two premises. It can be claimed, once a nation approaches the technological frontier, the characteristics of technological trajectories, national strategic focus, and organization of the formal standard-setting may create differences in the rates of national catch-up in formal ICT standards. This may be achieved by skipping some activities or processes of overall formal standard-setting process.

3.1. The possible transition trajectories

As latecomers make transition from the taking-off phase to the forging-ahead phase, a possibility of taking different paths is enabled by the milestones of formal standards-setting process (points X, Y, and Z in Fig. 2). Point “Z” marks the initiation of Planning for formal standards at ISDOs, which involves collection of interests, understanding and agreement of all members on a common agenda, and the direction for development and management of future standards. It is followed by Execution (initiated at Y), that is, developing and writing standards. The approved standards are made available to members for Implementation mostly on a voluntary basis (at point X), when firms start to produce compliant systems.

There are three possible transition paths which generally conform to the traditional RPC pattern of learning and catch-up, of which the first one (A: Gradual Stepwise) particularly conforms to the gradual RPC pattern of capability build-up. At first, in the mature phase, the knowledge for usage and production of systems is acquired through quality and productivity standards, where only essential interface standards are incorporated. Keeping up (fast follower status) is acquired once technology standards can be implemented relatively fast, generally with some level of localization. Once the mature systems development and generic domestic and international standards processes have been mastered, the next step for an organization is to develop its own systems technologies. Here, developing its interface standards by itself becomes imperative. However, latecomers approaching point X have normally learnt development of system products based on foreign standards without actually participating in setting standards. Hence, they lack capabilities to develop standards on their own. Little ownership of standards and unpredictable global diffusion can maintain some pressure for continued followership and implementation, so they can continue to learn and increase participation through points Y and Z over the next generation of standards.

However, continued access to and implementation of standards through fast-followership may not be a good idea because profitability remains low from their own implementations and rents go to others for core technologies (Intellectual Property embedded in standards). Therefore, improving execution stages may be imperative to raise. 

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8 In case of catch-up in technological capabilities, Lee and Lim (2001) demonstrated that stage-skipping and path-creating innovation is possible, for example in CDMA technologies and systems development in Korea. However, any examples of skipping for standards are not noted yet, either against the product cycle or standards-setting processes.
standards writing and development capabilities. Once learnt for a domain over repeated experiences, latecomers can jump (B: Skipping Implementation) directly to point Y with their own proposals in a related technology, even without essential implementation and diffusion capabilities in that technology domain. Such a trajectory is made possible by conscious acquisition and investment on knowledge either in the form of open upcoming standards plans or cooperation with other advanced players. Partial or full ownership of standards (essential IPR), higher level of knowledge in comparison to competitors and access to tacit knowledge embedded within the standards-setting process are the highest incentives in such a jump.

Thirdly, latecomers can participate directly in making proposals or contributions to planning of new standards for new anticipated technologies (C: Skipping Implementation and Execution). That would rest on deepened technological
capabilities in any core technologies, but standards capabilities for Implementation and Execution for at least one different system within a similar standards process and organization. However, if the proposed standards represent technological discontinuities, then no specific execution and implementation experience may be required, instead broader capabilities from related technologies and systems can be more relevant. The gaps require commitment of heavy resources in R&D and complex regional and international interactions with intention to manage new technologies and define new markets. The advanced knowledge of future technologies being discussed at ISDOs can help set the directions of R&D investments at the national and sectoral levels creating a virtuous circle of deepening and broadening frontier capabilities. Moreover, an organization’s own interests can be managed in global evolving technologies, for example, appropriability can be enhanced by embedding their own IPR into new standards in planning.

3.2. The sources of differentiation in rates of catch-up

3.2.1. Technological trajectories

The fact whether a new technology is a generational increment or a technological discontinuity is quite important. In the case of generational increments, the incentives are lower because IPR and standards for core technologies are already under the control of others. However, if the discussed platform capabilities exist, then technological discontinuities are attractive in terms of anticipated rents despite higher risks. For example, in shifts from wired to wireless systems, modulation and transmission technologies changed but the rest of the core technologies remained more or less the same, e.g. multiplexing and switching. Furthermore, the overall core building blocks are still comprised of user terminals, transceivers, modulators, multiplexers, switches, signaling & call management systems, and information databases requiring similar knowledge.

3.2.2. National strategic focus

The latecomer countries targeting learning and capability build-up may weigh benefits differently from those adopting standards merely for production. Also, the motives of technology creation and standards are not uniform as the level of catch-up changes. A very latecomer country may be seeking to learn through technology usage but a fast follower may also consider finding and penetrating new markets. If capabilities to develop their own standards are a necessary condition to win in markets, then latecomers coming from mature stages can remain trapped in low-profit implementations of recently standardized complex systems or satisfied with winning dominant designs for simple products. This is because anticipatory standards are the basis of evolution of technological trajectories and represent the technological frontier to an extent. They are formed prior to competition. Whereas single firms can be successful in standards for simple or single products, the formal standards capabilities for complex systems may never be fully developed without moving to the frontier, irrespective of the fact that broader design and production knowledge is well developed. Therefore, an organization may need strategic intent to move continuously up to the frontier, rather than deepening its own technological and standard capabilities up to the level of generation in selected technologies.

3.2.3. Organizing the standardization

Mastery of the generic standards process (Planning; Execution at specific SDOs or consortia; and Implementation including diffusion and generic standards capabilities to acquire, maintain, and adjust standards) is important but the process does not change quickly over a technology cycle. However, for each case, the collaborative or competitive nature of those activities may change or the preferences of the stakeholders may change for process (Hawkins, 1999). Formal anticipatory standards-setting through committees is generally perceived as a collaborative effort to reduce future uncertainties and control the technology evolution. Still, the interaction between regional and international stakeholders may create differences, especially within areas of grey-standardization at expert consortia and ISDOs (Egyedi, 1996); hence, state intervention and support significantly affects such variations. Moreover, formal standardization extensively requires many non-technological capabilities, for example, social, institutional, and political (Besen & Farrell, 1994; Mattli & Buthe, 2003; Schmidt & Werle, 1998). The differences in capabilities related to the multiple fronts may impact the choice for different trajectories.

3.3. Research methodology

In order to test the claims on possible transition trajectories to the technology frontier during standards catch-up, multiple case studies of ICT systems and standards by Korea are developed. First, Korean government documents and publications were used to identify strategic and major ICT projects and initiatives over the last two decades. That led to identification of four key ICT sectors for which a chronology was drawn in terms of technology and standards development. Journal articles on related keywords were sought through major database publishers9 to gain deeper insight of the systems or standards. Many archived Korean newspapers, magazine articles, Korean SDOs (especially TTA), and government publications were extracted from Korean and international web-based search engines.10 The cases were

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9 Elsevier ScienceDirect and Scopus.
10 Naver, Daum, and Google are popular search engines whereas EETimes, Korea IT Times, and Digital Times are popular IT news archives.
developed especially looking for data, events and their details relevant to the three factors claimed. In case of NGN and IPTV case, there was a little evidence due to on-going standardization. Therefore, technology leadership in core technologies was demonstrated through patent analysis rather than actual standards. The patent applications data from WIPO Patent Scope database was obtained and analyzed on core technologies for NGN/IPTV standards and previous standards by leading firms from leading nations or regions. Once completed, the rates of catch-up and variations were traced in each case and analyzed to determine if the results confirmed the proposed trajectories or otherwise.

4. Case studies

This section briefly introduces the Korean domestic standards and organizations to provide background for the discussion of case studies of ICT systems and their formal standardization. After that, four cases are presented, each of which includes smaller caselets covering few or all of the elements claimed in the framework. The analysis and conclusions for these case studies are presented in a separate next section.

4.1. The Korean ICT standards and organizations

There are three types of ICT standards and institutions in Korea: (1) Korean Industrial Standards (KS); (2) Korean Information and Communications Standards (KICS); and (3) Telecommunication Technology Association Standards (TTAS). The Telecommunication Technology Association (TTA), a non-government organization established in 1988, manages TTAS in relation to international standards by ITU and other regional SDOs and industrial consortia (Fig. 3). The KICS are domestic de jure standards that are not directly developed by public actors but require mandatory state approval from the Korea Communications Commission (KCC) after field trials. At the end of 2008, there were about 7577 TTAS and 601 KICS published (Telecommunications Technology Association (TTA), 2009a), an exponential increase compared to the very few standards in 1988.

4.2. Case study 1: Telecommunications Systems and Networks

Korea’s rapid learning and capability accumulation in ICTs are frequently attributed to two R&D projects for telecommunications systems: indigenous digital switching systems called TDX during 1982–1990s and subsequent world-first development and mass commercialization of CDMA systems around 1992–1997 (Fig. 4). Both were led by public actors (Choung et al., 2006; Mani, 2005; Mytelka, 1999) where the state also controlled the domestic market through standards (e.g. CDMA) (Jho, 2007; Lee, 1999). In parallel, market reform and restructuring for telecom and broadcasting was pursued leading to fully open market segments for foreigners’ entry by 2000 (Shin, 1995). However, local operators and manufacturers developed their own strategic interests, which differed from the state in 3G wireless technologies, visibly continued onto 4G.

![Fig. 3. Institutional structure and linkages for Korean ICT standards (as of 2008). Source: Compiled from KATS, TTA and ANSI publications.](image-url)
4.2.1. Digital switches for PSTN: indigenous development of TDX system based on TDM

In order to remove the demand backlog during the 1980s, Korean policymakers considered its own digital switching technology rather than relying on imports, with the rationale of saving costs and raising indigenous technological capabilities to reduce dependency on foreign switches (Lee, 1999). Although capabilities for microprocessor-based systems were largely missing, a few previous R&D successes (Memocall and 500-line pilot digital switch) and some production capabilities for electromechanical switches provided confidence to initiate the TDX-1 national project in 1982, which turned out to be a success by 1985. A series of projects for digital switches named TDX-1B, TDX-10, and TDX-100 followed over a period of just 15 years with increased capacity, functions, and compliance to global standards, e.g., SS7, C7, and ATM/ISDN.

4.2.2. 4G wireless: adoption, development, and commercialization of CDMA

Around 1990, the Korean Government considered wireless as the next generation technology to diffuse. In 1991, a ‘Joint Development Agreement’ was signed by Korean actors with Qualcomm Inc. and ETRI to develop and commercialize the CDMA system in Korea along with other manufacturers, operators, and research actors (West, 2001). CDMA was approved as IS-95 international standard by TIA only in July 1993. The Korean Ministry rejected GSM and declared CDMA the national standard in 1993 considering CDMA as the most efficient solution, fully developed and held by a single US organization. Qualcomm provided radio waveform and signal processing techniques while ETRI developed CMS, including Base Stations, Mobile Switching Centers, and Location Registers using TDX expertise (Shin, 1997). RTS was delivered by Qualcomm and tested in 1992–1993 (Han, Bak, & Yang, 1997), following which the technology was transferred to manufacturers who completed commercial testing by October 1995. The world-first commercial services for CDMA were launched in early 1996. The organization for R&D and technology development of CDMA (IS-95) was somewhat similar to TDX projects with little changes in proportions of inputs and output stakes of the private sector (Choung et al., 2006). CDMA was rapidly diffused in Korea, with around 9 million total subscriptions for cellular service by 1998 (Table 1). This made it the leading CDMA market after the USA.

4.2.3. 3G wireless: proposals for new asynchronous and synchronous CDMA

ITU requested proposals for IMT-2000 in 1996 to enhance the capacity and features for 3G cellular communications, following which a nation-wide consortium comprising 66 domestic and three foreign firms was established with participants of the CDMA project, new firms, and ETRI to develop IMT-2000 specifications (Wee & Shin, 1998). ETRI remained the R&D leader while KT dealt with Project Management. Manufacturers and operators soon realized that IMT-2000 would include multiple standards, and they anticipated that there would difficulties on the international scene with a single standard. They formed another consortium called Asynchronous Development Group (ADG) that developed alternate specifications, with ETRI as a passive participant. The efforts of the two consortia enabled TTA to propose in time two proposals out of ten received by ITU: CDMA I (a synchronous version closer...
to ETSI and ARIB proposals of WCDMA) and CDMA II (an asynchronous version closer to Qualcomm’s CDMA2000) (Fukuda, Noda, & Higuchi, 2002). Both were accepted by ITU in 2000 among five approved air interface standards for 3G.

4.2.4. 4G wireless: contributions to LTE and UMT based on OFDM and OFDMA

Since 2002, ITU has initiated planning for IMT Advanced systems (4G wireless) and two major standards evolved, that is, 3GPP backed Long Term Evolution (LTE) and 3GPP2 backed Ultra-Mobile Broadband (UMB). IEEE’s Mobile WiMAX is another candidate focused to bring broadband internet and mobility to cellular wireless networks. All three use OFDM/OFDMA (Orthogonal Frequency Division Multiple Access) as core transmission technologies. Whereas planning at ITU-R for 4G was concluded and execution of formal standards initiated since March 2008 and due to be finished in 2011 (Blust, 2008), Qualcomm withdrew in 2008 from any further development of UMB. Korean operators are not very aggressive with 4G pilot deployments, but along with ETRI, TTA, and manufacturers they are active members of 3GPP, 3GPP2, WiMAX forums. A first ever demonstration of LTE’s downlink was conducted jointly by Nortel Networks, US, and LG of Korea in 2008 in USA (Nortel, 2008). Similarly, Samsung modems were used for the world first launch of a partial 4G service at the end of 2009 in Stockholm and Oslo (Ricker, 2009).

However, it is difficult to measure the Korean success in these standards because the process is still going on and not completed. Nevertheless, it can be distinguished that Korea is emerging as a technological leader for core transmission technologies of future wireless and converged networks. For example, looking at the number of firms with at least 10 or 50 patent applications in core transmission technologies (Table 2), the number of Korean firms with at least 10 or 50 OFDM and OFDMA patent applications is more than number of USA, EU, and Japanese firms. This had not been the case previously.

Table 1
Subscriptions (in millions) for different services.

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<td>Mobile total</td>
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<tr>
<td>WCDMA</td>
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<td>0.17</td>
<td>5.99</td>
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<tr>
<td>Data comm. and internet</td>
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<td>Dial-up</td>
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<td>12.3</td>
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<tr>
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<td>0.2</td>
<td>0.38</td>
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<tr>
<td>Broadcasting</td>
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<tr>
<td>Cable TV</td>
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<td>1.3</td>
<td>2.8</td>
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<tr>
<td>T-DMB</td>
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<td>0.12</td>
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<td>S-DMB</td>
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<td>1.02</td>
<td>1.27</td>
<td>1.72</td>
<td>2.06</td>
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<tr>
<td>IPTV</td>
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</tbody>
</table>

‘Blank space’ means ‘not available’.
‘–’ means ‘no service’ or obsolescence.

Table 2
Technological capability gaps in core transmission technologies (IAs recorded till Dec. 2008).
Source: Authors’ compilation from WIPO Patent Scope Database (as of 2008).

<table>
<thead>
<tr>
<th>Technology-wise number of patent applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDMA IAs</td>
</tr>
<tr>
<td>≥ 10</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Numbers of firms/organizations from</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
</tr>
<tr>
<td>Japan</td>
</tr>
<tr>
<td>EU</td>
</tr>
<tr>
<td>Korea</td>
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<tr>
<td>China</td>
</tr>
</tbody>
</table>

IAs: IPR applications, OFDM: orthogonal frequency division multiplexing, OFDMA: orthogonal frequency division multiple access. Just for example, the data in the top row and first two column of table shows “The number of US firms with at least 10 patents in TDMA technologies was 1, and number of US firms with at least 50 patents in TDMA technologies was 1”.

to ETSI and ARIB proposals of WCDMA) and CDMA II (an asynchronous version closer to Qualcomm’s CDMA2000) (Fukuda, Noda, & Higuchi, 2002). Both were accepted by ITU in 2000 among five approved air interface standards for 3G.

4.2.4. 4G wireless: contributions to LTE and UMT based on OFDM and OFDMA

Since 2002, ITU has initiated planning for IMT Advanced systems (4G wireless) and two major standards evolved, that is, 3GPP backed Long Term Evolution (LTE) and 3GPP2 backed Ultra-Mobile Broadband (UMB). IEEE’s Mobile WiMAX is another candidate focused to bring broadband internet and mobility to cellular wireless networks. All three use OFDM/OFDMA (Orthogonal Frequency Division Multiple Access) as core transmission technologies. Whereas planning at ITU-R for 4G was concluded and execution of formal standards initiated since March 2008 and due to be finished in 2011 (Blust, 2008), Qualcomm withdrew in 2008 from any further development of UMB. Korean operators are not very aggressive with 4G pilot deployments, but along with ETRI, TTA, and manufacturers they are active members of 3GPP, 3GPP2, WiMAX forums. A first ever demonstration of LTE’s downlink was conducted jointly by Nortel Networks, US, and LG of Korea in 2008 in USA (Nortel, 2008). Similarly, Samsung modems were used for the world first launch of a partial 4G service at the end of 2009 in Stockholm and Oslo (Ricker, 2009).

However, it is difficult to measure the Korean success in these standards because the process is still going on and not completed. Nevertheless, it can be distinguished that Korea is emerging as a technological leader for core transmission technologies of future wireless and converged networks. For example, looking at the number of firms with at least 10 or 50 patent applications in core transmission technologies (Table 2), the number of Korean firms with at least 10 or 50 OFDM and OFDMA patent applications is more than number of USA, EU, and Japanese firms. This had not been the case previously.
for CDMA or TDMA technologies in which Korea lagged behind number of USA, EU, and Japanese firms. That depicts inherent potential of Korean organizations to register more essential patents while the standards are being finalized.

4.3. Case study 2: Data Communications Systems and Networks

This section covers the development of commercial internet in Korea since the early 1990s, ultimately leading to proposal of its own wireless mobile internet standard named WiBro which was developed during 2002–2005 (Fig. 5).

4.3.1. Narrowband and broadband data networks: IP, ATM, and ISDN

During the early 1990s, the Korean government initiated mega national projects for informatization and national information infrastructures worth billions of dollars (Shin, 1995; Tcha, Park, Chang, & Song, 2000), which included high-speed backbones and communications infrastructure for the emerging internet (TCP/IP). A parallel increase in capacity, features, and data network interfaces was also carried out in TDX-10 and TDX-100 projects. Over 1992–1998, the majority of domestic standards for telecom networks, informatization, and network management were adopted from foreign sources (TTA, 2009a). The market has been open for DSL since 1995 and for high-speed internet only since 1998; while real broadband internet services (HDSL and FTTH) have been widely available and diffused since 2000. The diffusion of both narrowband and broadband internet in Korea has been one of the most rapid in the world (Table 1).

4.3.2. Wireless broadband and mobile wireless broadband systems: WiMAX and WiBro

Wireless Broadband (WiBro) is a Korean internet technology developed by a consortium of ETRI and private corporations, Samsung, KT, SK Telecom, etc. It is compliant with IEEE 802.16 specifications of 2004 and commonly promoted as WiMAX. As markets in voice and data approached saturation (Table 1), suppliers and the Korean government sought new markets to sustain ICT-based growth. The IEEE 802.16 standards were announced in 2000 but systems were not implemented or in production. This sounded like an opportunity if complemented with mobility, so the Korean government provided an impetus for entry by allocating 100 MHz of spectrum in 2.3–2.4 GHz band at the end of 2002. TTA initiated selection of standards by engaging 235 members for different groups and committees from 52 organizations. It tested two OFDM and two non-OFDM systems in late 2003, and OFDMA technology was selected as the baseline in March 2004 based on IEEE 802.16 specifications (Telecommunications Technology Association (TTA), 2009b). The Service and Network Working Group of TTA PG302 developed a service and network requirements document and network architecture model. By June 2004, Phase 1 of WiBro domestic standards was completed laying down major system parameters and service characteristics (Wireless Broadband, n.d.). It did not use the same frequency band used for wireless broadband in other countries based on IEEE standards. Phase II for WiBro was launched with enhanced objectives, of which major was harmonization with IEEE 802.16 specifications. It resulted in an updated version around mid-2005. MIC announced WiBro as a compliant technology to WiMAX in December 2005, when TTA sent a letter to WiMAX Forum on this (Telecommunications Technology Association (TTA), 2009c). The WiMAX Forum accepted the position of WiBro so when IEEE802.16e was proposed to ITU-R as an IMT-2000-air interface, WiBro was specified as “one of the SDO profiles technologies/projects

![Fig. 5. Evolution of data communications technology development and standards in Korea. Please see note 1 under Fig. 4.](image-url)
defined for the recommended interoperability parameters”. WiMAX was accepted as the sixth IMT-2000 (3G wireless communications) standards by ITU during October 2007 paving way for its diffusion.

4.4. Case study 3: broadcasting systems and networks

Broadcasting is a different industry from telecom, although customizable individual services are converging due to digitalization, broadcasting networks deliver content and information to multiple users simultaneously rather than connecting individual users. Therefore, the complexity is lower for switching and transmission but much more for signal/media processing and content generation. Till the early 1990s US-originated NTSC and European PAL and SECAM remained the key analog broadcasting standards. Digital Television (DTV) standards started to be ratified during the mid-1990s with DVB coming from Europe and ATSC from the US. Japan switched from NTSC to DVB for terrestrial DVB standards but then went onto proposing its own standards related to quality of digital broadcasting, that is, high definition (HD). Korea was using NTSC, but during the transition to digital broadcasting in late 1990s, it suddenly jumped into global standardization with its own mobile digital broadcasting standards, namely Digital Multimedia Broadcasting (DMB). Korea had adopted ATSC for general digital broadcasts, yet initiated a national R&D project to develop and standardize DMB (Fig. 6). It turned out to be a success in December 2007 when ITU approved T-DMB as one of the global digital broadcasting standards. Nowadays, Korea and China are the key adopters with many others evaluating the option.

4.4.1. Media decoding and compression: MPEG technologies

Since 1988, MPEG standards have defined the digital compression formats of audio and video for motion pictures, that is, MPEG-1, MPEG-2, and currently MPEG-4. ETRI and other players took much interest in the R&D of encoding and decoding of media with increased signal processing capabilities gained from telecommunication systems and products development. As a result, Korean firms were able to secure the majority of essential patents for the new MPEG-4 standards during the late 1990s, establishing a partial technology leadership (Choi & Choung, 2006).

4.4.2. Digital TV: choosing ASTC or DVB technologies

There were two major anticipated digital televisions (DTV) standards, the US’s ATSC and EU’s DVB. In the 1990s, DAB had already been selected in Korea for digital radio broadcasting with domestic standardization in progress, but in the case of TV, stakeholders had reservations about ATSC and DVB. Koreans observed developments in the US, Europe, and Japan on digital broadcasting standards clearly noting that ATSC offered high definition picture quality (HD) but exhibited limitations in mobile reception, whereas DVB was competitive in mobility but for picture quality was limited to standard definition (SD). A national debate took off due to the variety of stakeholders, that is, the state, manufacturers, broadcasters, and to some extent telecom operators, that comprised the political and social dimensions as well as the economic (Choung et al., 2010). Korea adopted ASTC technologies for general broadcasting but realized an opportunity in mobile broadcasting due to the shortcomings in the available global standards.

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**Fig. 6.** Evolution of broadcasting/media technology development and standards in Korea. Please see note 1 under Fig. 4.
4.4.3. Mobile digital media broadcasting: T-DMB on top of DAB

DMB is a Korean proposed system-level formal standard for mobile broadcasting based on ETSI’s Eureka-147 or DAB standard. It adds video to the digital audio and provides better reception than the original DAB in difficult conditions, e.g., densely located buildings and moving vehicles. The project was conceived during debates over DTV but was initiated only around 2002. Korean MIC provided funding and institutional support for technology development, while TTA managed the standardization process. ETRI led the R&D with the key national broadcaster Korean Broadcasting System (KBS) and manufacturers holding MPEG-4 patents. Prior to their engagement in this field, Ministry of Commerce, Industry, and Energy (MOCIE) was the main government ministry related to the broadcasting industry, which had been promoting DAB. However, on confirmation of the potential of multimedia over DAB, they shared tasks with other ministries; MIC took charge of systems, hence gaining control over T-DMB development and standardization, while MOCIE focused on terminals and service. The division of labor reflected the accumulated knowledge and experience (Choung et al., 2010). The first Korean domestic TDMB standard was published in 2003 followed soon by around 50 standards. T-DMB was approved by ITU in 2007 making it the second major systems level formal standard of Korea. It was commercialized in three countries and was being tested by many as of December 2007 with subscriptions in Korea of around 10 million (Table 1).

4.4.4. TTI applications for mobile broadcasting: TPEG over TDMB

TPEG is a global standard developed by the TPEG Forum to provide digitized Traffic and Travel Information (TTI) to users independent of the device or service used, for example, road traffic situations, public transport information, and location referencing. It is being extended to cover congestion, parking, weather, etc. Its predecessor standards were Radio Data Services (RDS) for data over FM by European Broadcasting Union (EBU) and EN50067 by CENELEC. B/TPEG initiated development of TPEG around 1998, whose specifications were completed, made public, and submitted to CEN/ISO in 2002. In 2000, IEC also published a global standard covering complete RDS functionality. The European Union (EU) designated in 2000 a TPEG project to formalize TPEG concepts and the industrial development of a TPEG client decoder for continued development and maintenance of which the TPEG Forum was formed in 2003.

In Korea, the T-DMB national project was in market trials and all stakeholders were interested in its success and searching for killer applications. As TPEG was a well-developed option for TTI using DAB, Korean actors extending TPEG so that they could put in on top of their own DMB system backward compatible to DAB. They were also ahead in demand and diffusion of mobile internet applications. TPEG could provide a head-start to engage in development of killer applications for TTI and telematics.

In 2002, standardization for such a TTI service was initiated. TTA was following developments of DAB at ETSI, whereas KATS, a government standards body supported by the Korea TPEG Forum was tracking developments in ISO/IEC standardization on TTI in parallel. They planned to develop technologies following this original EBU path. ISO published two Key TPEG standards in 2006 when MIC and MOCIE decided to collaborate for standardization on TTI, especially TPEG. The Ministry of Communications and Transport (MCT) had already prioritized TPEG-CTT in May 2005. By the end of 2006, TTA (then under MIC) published seven TTAS standards while KATS (under MOCIE) published five standards (Choung et al., 2010; TTA, 2009a). The R&D activity and output of Korean firms and organizations has taken off since then, as indicated by their number of patent applications. It was in TPEG-CTT where Korean domestic standards contributed location referencing into ISO standards. In 2008, the physical format for link-node references used and proposed by Korea was adopted in ISO17572 (Intelligent transport systems-ITS, location referencing for geographic databases). Despite success in global standards and T-DMB receivers in Korea touching 10 million in two years time, the global diffusion of TPEG has been delayed.

4.5. Case study 4: NGN and IPTV

4.5.1. Next Generation Networks

Next Generation Networks (NGN) refers to future networks mainly based on IP technologies, which will provide different transport technologies for seamlessly delivering any services. However, it does not make a complete case due to the on-going planning and execution activities for standards. The standardization activity in this area was initiated by ITU through the NGN Focus Group (NGN-FG) in 2004 concluding at the end of 2005 (International Telecommunications Union (ITU), 2009). By then, Korean proposals and contributions totaled about 12% of the 988 documents (Telecommunications Technology Association (TTA), 2006) making it a leading contributor to global standardization and signifying its upgraded global vision and collaborative standards planning capabilities for idea search, selection, and development of future technologies at all levels. Furthermore, in 2008 the number of Korean firms with at least ten or more patents in core transmission technologies for 4G LTE (i.e. ODFM/OFDMA) was highest than any other nation in the world, which confirms their technological leadership and hence potential for success in securing essential patents for these standards (Table 2).

4.5.2. Internet Protocol Television over NGN

IPTV represents multimedia services delivered primarily on IP networks becoming closer to NGN over time. The focus group IPTV-FG was setup by ITU in 2005 with a mission to coordinate and promote development of global IPTV standards. Koreans entered the focus groups from the beginning showing high interest and performance in IPTV standardization. For example, in May 2007 Korean organizations proposed about 40 of the 184 documents at the fourth meeting, many for
system-level requirements and architecture (ITU, 2009). Korea was the only country with a sizable official delegation comprising around 30 delegates suggesting seven standards based on Korean patented technologies, along with 26 other proposals (TelecomWeb, 2007). Since 2008, it has been at the forefront of trial implementation of new IPTV services. Also in 2008, Korea was awarded the chairmanship of working groups SG13 (future networks including mobile and NGN and IPTV), evidence of rising influence at international SDOs in these frontier domains.

5. Case studies analysis and conclusions

5.1. Path A, gradual step-wise accumulation: Telecommunications Systems and Network

The series of success in TDX systems helped Korean national system to accumulate technological capabilities. Moreover, infrastructure was established for developing and producing own systems, automated testing, and software development around foreign mature technologies although with little of design capabilities of core components like microprocessors (Hwang, 1986). Nonetheless, TDX-1A and TDX-10 largely fulfilled domestic demand, increasing pressure on later projects to target exports and hence on compliance to the latest global standards. However, no international standardization efforts have been visible during these projects; ETRI developed and published few domestic software and system-level standards. After 1988, TDX projects started incorporating new standards like ATM and ISDN.

In the case of CDMA, Korea did not own core technologies and the fate of CDMA diffusion was not known, but investments in evaluating CDMA were visible even before 1989 (Han et al., 1997). The standards capabilities of the Korean system were extremely limited as the infant TTA struggled to manage harmonizing the needs of ‘National Network Infrastructure’ and informatization projects (TTA, 2009a). The creation of ETSI in Europe and TTA in Korea was in same year (1988) with ETSI’s primary responsibility to develop GSM standards. Whereas both the US and Japanese delegates joined GSM development at ETSI without any bitter debates (Haug, 2002), TTA did not join, which was indicative of the Korean will towards CDMA. It was not only due to realization of higher returns from higher risks but also the strategic approach to try for partial ownership of new global standards. However, path-dependency, technology relatedness, and advantage of complementarities from TDX cases played their roles, for instance, the 2G system had to run with existing PSTN and not to substitute it in the near future. Secondly, core technologies were important but Han et al. (1997) show the TDX-1/10 switching system was modified to serve as a ‘Multiplexer’, a core part of the ‘Call Management System’. The availability of low-cost semiconductor components and PCB manufacturing combined with Qualcomm’s isolation in international standardization met perfectly with Korean ambitions and capabilities. Hence implementation of an upcoming global standard became a viable opportunity to participate and learn formal standardization rapidly, along with main intention of strategic transition towards leadership in systems development.

The dominance of GSM raised doubts about the single standard strategy; therefore Korean actors submitted two proposals for 3G. These rested on TDMA and CDMA capabilities acquired from two key projects, but they still had to develop additional knowledge of transmission of wireless TDMA. Moreover, no major discontinuity was expected in wireless cellular technologies and equipment rather than developing its own. Nevertheless, IP networks were widely adopted and deployed. However, on the context of internet and mobile services peaked, requirements of new markets and services opened up new opportunities.

5.2. Path B, skipping standards implementation: Data Communications Systems and Networks

Due to limited resources, latecomers find it difficult to invest in multiple technologies. Korea did not invest in R&D for IP technologies due to path-dependency limited R&D resources prioritized for TDX, ATM/ISDN, and CDMA projects. That left it with rapid implementation and raising national capacity for TCP/IP data communications through imported technologies and equipment rather than developing its own. Nevertheless, IP networks were widely adopted and deployed. However, once diffusion of internet and mobile services peaked, requirements of new markets and services opened up new opportunities.
The development of Korean WiBro represents a jump from usage of mature IP technologies directly to the execution stage of global standards. It was the first ever national R&D project targeting formal international standardization in the early phases of the technology cycle. However, instead of developing from scratch, Korean players focused on speedily improving efficiency, capacity, and mobility of an open global standard (IEEE 802.16) with their deepened OFDMA capabilities. The success in skipping implementation rests on technological relatedness of systems knowledge between two domains of telecommunications and data communications networks and other systems development capabilities.

Secondly, strategic intent to own standards for defining global markets is visible from revamping of national standardization policy around 2000 and setting up more than 20 domestic industry forums for IT standards (TTA, n.d.). Although development of the WiBro system was done by an organization similar to that for CDMA, standardization was taken care of by TTA in close interaction with ETRI. The communications show TTA initiated it by informing IEEE of their efforts on WiBro standards and requesting mutual collaboration (TTA, 2009c). The speedy standardization of WiBro pushed IEEE somehow to move faster and collaborate also. The later declaration of WiBro's compliance to WiMAX did not receive much argument by IEEE; rather support by the WiMAX forum was extended to Korean TTA, recognizing it as the world's second WiMAX certification lab.

5.3. Path B, skipping standards implementation: broadcasting systems and networks case

During transition to DTV, DMB emerged as a result of mediation on social and political contexts, but technologically speaking, it was a successful transition to leadership by proposing new global standards for anticipated needs, ahead of time. An opportunity was exploited speedily filling in holes in open global standards based on Korean firms' technological capabilities in MPEG-4 and systems, which represents a jump directly to the execution stage of global standards for digital broadcasting. The Korean perception about EU countries was they would adopt T-DMB, because they were still evaluating and installing DAB infrastructure and the benefits from compatibility and low-cost video capabilities would be quite attractive. However, once Koreans made proposals for T-DMB to ITU, it appears that the relationship with DVB-H turned into kind of competition. An earlier commercialization was significant so Koreans pushed on with fast development and implementation. However, they had fewer capabilities to gather regional cooperation and buy-in for diffusion like ETSI. That implies, making such jumps require or push to build additional standards capabilities, other than technological capabilities. Nevertheless, the strategic intent of the government at a higher level had clearly turned from mere learning and raising technological capabilities towards finding new ICT-based growth engines, indicated by the comprehensive IT-839 strategy and first long-term standardization roadmap of 2004, which included DMB as a core technology.

Apparently, the objective of the TPEG standardization effort by Korea was to ensure a global market share for DMB in addition to uplifting the domestic diffusion. It was pursued through a non-traditional path, that is, a search among frontier standards plans, identification of a potential niche, and linking Korean proposed T-DMB and related domestic technological capabilities. The first Korean patent related to methods for TPEG data service was filed with USPTO by Samsung Electronics in 2005, which was followed by a number of patent applications by multiple players. Yet, selection of a niche, that is, ‘Congestion’ and ‘Travel-Time Applications’ (TPEG-CTT for location referencing on geographical databases) demonstrate newer capabilities, which seem to stem from a combination of expertise in commercialization and market control of wireless telecommunications, broadband internet, and T-DMB. The process knowledge and institutional links this time were different yet available from other organizations, e.g., KATS, which is responsible for standardization at ISO. That led to new TPEG proposals to ISDOs in planning stages and followed the previous jump from a fast-follower of digital broadcasting technologies. The non-state actors are seen to be involved more in planning and development of domestic and global standards than any previous case.

5.4. Path C, skipping standards implementation and execution: NGN and IPTV case

The Korean IT-839 strategy of 2006 included IPTV and NGN as core technologies (called Broadband Convergence Network or BcN in Korea). The first Korean IT standardization roadmap of 2004 was in line with policy and was also reflected in annual updates and development of the next standardization roadmaps for 2008 and 2010 (TTA, n.d.). Hence, a clear strategic focus on IPTV, NGN, and 4G standardization at ISDOs emerged in order to strengthen technological leadership and gain access to future global markets. However, these network technologies and systems are highly complex in scope, making it impossible for any single nation, consortia, or organization to own large chunks of standards. Hence, being an active part of global collaborative efforts, it is vital for taking care of one's own interests and gaining tacit knowledge to compete in development of systems, once standards are fixed and adoption takes off. Moreover, Korean repositioning on WiBro could be strategic but was evident of weakness on institutional and political fronts, which also partly explains active Korean contribution to future technologies rather than proposing its own system standards.

5.5. Conclusions

Summing up the analyses from each of the cases, few observations are made. At first, a reverse pattern against product cycle is confirmed for standards catch-up for all cases. However, there are differences in paths taken for formal standardization (Table 3). The four cases studied can be observed to follow at least one of the three proposed paths;
Table 3
National level trajectories in ICT standards in Korea based on where they were initiated and carried on during the phases of technology cycles.

<table>
<thead>
<tr>
<th>Product Cycle Phase</th>
<th>Fluid</th>
<th>Take-Off</th>
<th>Mature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formal Standards-Setting Phase</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Transition Trajectory</td>
<td>Case</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A: (Gradual Step-Wise)
- **Telecommunications Systems and Network (Digital)**
  - **4G Wireless; LTE (OFDMA)**
  - **3G Wireless; WCDMA, CDMA2000 (CDMA, TDMA)**
  - **2G Wireless; (CDMA)**
  - **SS7, C7, ATM, ISDN (TDM) for PSTN Digital Switches**

B: (Skipping Standards Implementation)
- **Data Communications Systems and Networks**
  - **Advanced WiBro, WiBro for IMT (OFDM/OFDMA) Mobile Broadband Internet**
  - **WiBro (OFDM/OFDMA For Mobile Broadband Internet**
  - **TCP/IP + IPv6 for Fixed Broadband Internet**
  - **TCP/IP for Fixed Narrowband Internet**

B: (Skipping Standards Implementation)
- **Broadcasting Systems and Networks**
  - **TPEG over T-DMB TTI Application for Mobile Broadcasting:**
  - **MPEG-4 for Advanced Media Compression;**
  - **MPEG-1, MPEG2 for Media Compression;**
  - **Digital Audio; DAB, Digital Terrestrial TV; ASTC**
  - **NTSC for Analog TV**

C: (Skipping Standards Implementation & Execution)
- **Next Generation Networks and IPTV**
  - **Next Generation Networks: NGN & IPTV over NGN**

Blank white boxes represent the skipped steps; Gray boxes represent the obsolescence/non-existence of the technology trajectory.
Digital Telecommunications Systems and Networks case followed Path A, whereas two cases of Data Communications Systems and Networks and Broadcasting Systems and Networks followed Path B. The latter show a jump to own proposals of formal standards i.e. WiBro and T-DMB, and there is no evidence of own standard implementations of new technologies before that, like CDMA in the first case. In case of NGN and IPTV, overall capabilities rely on all the previous developments, but Korean actors contributed more than participants from any single nation since the planning started for a new network technology concept. That makes it a direct entry into the planning of global standards-setting, confirming to Path C in the framework.

Secondly, overall timelines for each case coincide to some extent, but the rates of catch-up are different for each case only once a minimum level of capabilities are accumulated for both mature and somewhat new technology standards. That establishes formal standardization as one of the sources, which can speed up the transition to frontier. Being a leader (national) at technology frontier will not be result of a single heroic but repeated demonstration of the capabilities.

Lastly, the formal standardization milestones are found to be pivotal in defining the transitions, which associate with few commonalities and differences in characteristics of technology, national strategic focus and the national level organization for standards-setting (Table 4). An approach of long-term competitiveness was taken i.e. Path A for technologies improving gradually without major disruptions. This required strong government guidance in the initial phases, ultimately shifting to support of market guided requirements. Contrarily, technologies which were disruptive or required larger change could take Path B or Path C. In such cases, national focus is on locating and tapping any technological or market windows of opportunities earlier than competitors, or trying to define new markets. In these cases, organization of standardization at national level requires active role and contribution of private sector with government as a supporter. However, the different paths and their common basis are not exhaustive and need further confirmation from other latecomer nations.

6. Discussion and implications

In general, the analysis and conclusions of case studies imply that the role of standards-setting and management is increasingly significant for faster learning, especially when approaching the technology frontier. This should be a strong consideration by second-tier catching-up countries when they create their strategies for building complex systems and related standards. There are few points to consider in particular.

At first, some level of technological and standards capabilities for usage and improvement of complex systems accumulated by a national system can serve as a common platform for other systems. Without investing heavily in developing systems and standards in many sectors, it may be possible to develop new systems and standards if core technologies can be developed or gained access to. Such platform and complementary capabilities are enough for fast-followership of newly created open standards, due to which profitability from implementations would remain low.

However, at each instance of generational change or technological discontinuity, latecomers face the same challenge of selecting the right standards to implement without any control over its diffusion. On the other hand, development of systems at the frontier rests on ownership of core technologies and advanced architectural knowledge besides interface standards compatible with competitors’ systems and networks. Some latecomers who want to be technology and market leaders choose to strategically develop newer systems and standards by managing formal standardization based on identified elements. Even so, as a result of possible skipping of certain capabilities they may face consequences in terms of higher uncertainties about competitor behavior and market diffusion.

The role of platform knowledge and complementary assets is equally available for all new system-level efforts and projects. If the degree of expected technological change on a trajectory is high (discontinuity) and there is strong
technological relatedness, latecomers with essential platform capabilities are more likely to try for the frontier. If knowledge and capabilities for core technologies are weak and also inaccessible, skipping to advanced points becomes risky and difficult because no open standards are available. Thus, taking a fast follower path may depend on other factors like strategic focus. However, for generational technology changes, because sufficient knowledge could be acquired by implementation of previous generations, it is comparatively easier to enter directly into the development or planning stages.

The direction of the overall national strategy towards innovation and technological development and standards plays an important role. It implies whether a latecomer wants to keep on following or invest in becoming a technology leader and paying the due price. Given the choice to become a leader, the tendency for taking higher risks can be present in earlier phases of the technology cycle, as the state is inclined to rapidly raise technological competitiveness in this case. However, such tendencies may shift towards speedy entry into new markets and searching new markets through management of technology evolution in advanced phases. Often de jure standards and regulation is required to control market growth. But the interests and strategic perceptions about the market may diverge between actors from private sector and state. Therefore, they may be some friction between the two in planning for entry and definition of new markets, especially when acquired platform knowledge is used to develop systems and standards in a related but different sector.

Lastly, the process and arrangement of organizing actors and interactions in global standards-setting is important. A strategic aspect can mount pressures for competitive or collaborative strategies with major actors. For example, in earlier stages due to the non-availability of its own IPR and core knowledge, one has to take sides in global competition for access to core knowledge. However, as technological capabilities and understanding of global technology and market landscape increases, cooperative positioning within global standards-settings may be inevitable. Moreover, organizations and their linkages reflect on both the breadth and depth of understanding and management of a number of standards-setting processes of disparate SDOs. The type of linkages determines both technical and non-technical (especially political) recognition of participants within these processes. This implies more than simple participation at a targeted sector specific SDOs. One has to engage actively with different actors in different relationships, for instance, mutual recognition, joint development, expert opinion exchanges, etc.

The merits of transitions and related strategies in terms of how they affect diffusion are something not targeted in this paper. Unexpected diffusion rates despite successful formal standards imply a need for further research to shed light on the strategic space in relation to capabilities for innovation and diffusion of complex ICT systems. A recent effort in this direction is (Choung et al., 2010), however, more case studies from developing countries and other sectors are required to establish concrete basis of standards-setting by latecomers.

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References
