The Co-Evolution of Technology and Methods of Standard Setting: the case of the mobile phone industry

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Abstract

This paper applies the concept of co-evolution to technology, institutions, and industry structure in the mobile phone industry with a focus on technology and the institution of standard setting. The paper finds that technological change has caused the method of standard setting to come full circle. Technological change initially supported the move from quasi-vertical integration to an open standard setting process in both wireline and mobile phone systems where changes in the method of standard setting lagged the changes in technology. Growth in those markets that initially implemented an open standard setting process in mobile phone systems encouraged other countries to adopt similar types of standard setting where government agencies and firms were the mechanisms for this transmission of open standard setting methods. However, technological change in the form of the mobile Internet has caused quasi-vertical integration to return in the form of service providers determining the mobile Internet standards and the specifications for the phones that support their mobile Internet services. Again changes in the method of standard setting are lagging changes in technology and a new set of firms is transmitting these methods of standard setting to the rest of the world.

Keywords: technology, evolution, transmission, standards, global,

JEL Classifications: L15, L22, L43, O30, O32, O33

1. Introduction

Evolutionary theorists have long been concerned with the interaction between technology, institutions, and industry structure, and why some countries implement institutions and industry structure that support economic growth faster than other countries (Schumpeter, 1942; Rosenberg, 1976; Nelson and Winter, 1982). Nelson (2002) emphasizes the role of routines and the role they play in both technological change and institutions where it is the evolution of these routines that determines economic growth.

Strategic management theorists use different terms to represent similar concepts. Although they also use the terms technology and industry structure, they often use the terms process and organizational structure instead of routine and institution respectively (Mintzberg, 1978). For example, Henderson and Clark's (1990) contingency model emphasizes the need for different processes and forms of organizational structures to handle different forms of technological change such as integral versus modular problem solving. And because most industries undergo a gradual evolution from integral to modular problem solving over time, particularly as a dominant design (Abernathy and Utterback, 1978; Anderson and Tushman, 1990; Utterback, 1994) emerges, firms tend to develop processes and organizational structures that support modular problem solving. These processes and structures can act as "core rigidities" for innovations that occur less frequently (Leonard-Barton, 1992; Christensen, 1997) and that require a different form of problem solving such as integral problem solving (Clark and Fujimoto, 1991; Chesbrough, 2003).

Whether we use the terms of strategic management or evolutionary theory, co-evolutionary models can help us understand the interaction between technological change, institutions, and industry structure (Lewin et al, 1999; Nelson, 1995; Ziman, 1999). Recent work on co-evolution has called for analysis of both directions of causality (Pelikan, 2003), stricter definitions of co-evolution, and their application to institutions as opposed to merely firms (Murmann, 2003).

This paper applies the concept of co-evolution to technology, institutions, and to a lesser extent industry structure in the mobile phone industry where standard setting is considered the key institution. Although there is a substantial literature on standard setting in many industries (Grindley, 1995; David, 1987; Shapiro and Varian, 1999; David and Steinmueller, 1994), the network effects associated with these interface standards (Katz and Shapiro, 1986; Farrell and Saloner, 1985), the impact of standard setting on competition between firms (Katz and Shapiro, 1985; Katz and Shapiro, 1994) and between countries (Funk and Methe, 2001), and the role of standard setting as a quasi-legal institution (Antonelli, 1994), little of this research has looked at standard setting as an evolutionary process or the effect of technological change on the appropriate method of standard setting. This is in spite of the fact that standard setting and the numbers of institutions that support standard setting have dramatically increased over the last fifty years in a wide range of industries.

This paper uses the mobile phone industry to demonstrate this co-evolution of technology and standard setting because there have been several technological changes during the last 25 years in this industry and standards have played a critical role in each of these changes. The unit of analysis is the method of standard setting, the method of standard setting can be considered a set of routines, and Durham's (1991) model of evolutionary change is used to characterize the evolution of standard setting including the methods and processes of transmission of these standard setting methods. As subsets of the main interaction between technological change and the method of standard setting, this paper also considers their interactions with competition and patent policy, which can be considered outputs from institutions, and with industry structure. This paper uses a narrow definition of industry structure in order to differentiate it from standard setting. It defines industry structure in terms of whether a service provider does the majority of research and development work or whether other firms such as manufacturers do.

With respect to technological change and the method of standard setting, this paper finds that changes in the method of standard setting have lagged changes in technology where the changes in technology have enabled new forms of problem solving. Of greatest interest, the evolution in problem solving and standard setting has been a circular rather than a uni-directional process. In the first three generations of mobile phone technology, there was a gradual move from integral to modular problem solving and the emergence of standard setting processes that support this modular problem solving. The most recent technological change, however, the mobile Internet, requires integral problem solving and this has caused the emergence of a method of standard setting that is similar to what existed in the wireline industry in the late 1970s.

2. Previous research

Beginning with Penrose (1959), management scholars and later strategic management theorists have emphasized that organizational structure should match the underlying technology and they have created many types of contingency models to support this notion (Mintzberg, 1978). For example, Henderson and Clark's (1990) contingency model emphasizes the need for different forms of problem solving in modular and architectural innovations. Architectural innovations require different forms of processes and organizational structure than do modular ones where scholars use terms such as “integral problem solving,” to describe the type of problem solving that is needed to handle architectural innovations (Clark and Fujimoto, 1991; Iansiti, 1997; Chesbrough, 2003; Steinmueller, 2003).

Other management scholars have focused on the ability of firms to change. Some argue that organizations possess some capacity to adapt to changing environments (Nelson and Winter, 1982; Nadler and Tushman, 1997; Teece, Pisano, Shuen, 2000). Others argue that firms tend to develop processes that support for example incremental and modular innovations and these processes act as a “core rigidity” for architectural and other innovations that occur less frequently and that require other integral problem solving (Leonard-Barton, 1992; Christensen, 1997; Chesbrough, 2003).

Evolutionary theorists also consider the ability of firms and other institutions to change. Nelson and Winter’s (1982) groundbreaking research on evolutionary theories of technological change emphasized routines. Some of Nelson’s (1995) subsequent research has emphasized co-evolution and the interaction between social and physical technologies where the concept of routines is used to describe these technologies. For example, the social routines of economies of scale and professional management only became productive at the end of the 19th century because they were needed by the new physical routines of mass production (Nelson, 2002; Chandler, 1962). Similarly, the commercialization of synthetic dyestuffs required new physical routines of synthesis and new social routines of organizing chemists in the laboratory and training them in universities (Nelson, 2002; Murman, 2003).

The concept of social and physical routines can also be applied to standard setting. The growth in the broadcasting, computer, electronics, telecommunication, video and audio recording, and related industries in the 20th century has increased the importance of physical routines such as the definition of standards and the importance of social routines such as those of standard setting institutions. These standard setting institutions range from government bodies such as the U.S. National Institute of Standards and Technology to international organizations such as the International Telecommunications Union, professional organizations such as the Institute of Electric and Electronic Engineers, and multi-firm coalitions that are created to support specific standards for example for audio or video recording (Farrell and Saloner, 1988; David and Steinmueller, 1994; Shapiro and Varian, 1999). The range of standard setting institutions reflects the large variety of social routines that can be defined for them.

The large variety of these social routines and the standard setting institutions they are found in suggest that the concept of managerial contingency models can also be applied to institutions such as standard setting ones. Just as firms must match the processes and organizational structure to the method of problem solving, firms either by themselves or in alliances with other firms and governments must also match the social routines of standard setting to the method of problem solving where this paper focuses on the difference between modular and integral problem solving. And drawing parallels with the organizational change literature, this paper uses the concept of co-evolution to consider how these methods of standard setting evolve along with the technology. It defines the evolution of standard setting in terms of Durham's (1991) five aspects of evolutionary change: 1.) units of transmission; 2.) sources of variation; 3.) mechanisms of transmission; 4.) processes of transformation; and 5.) sources of isolation.

3. Methodology

This paper primarily relies on published research on wireline (Brock, 1981; Brock, 1994: David and Steinmueller, 1994; Fransman, 2002), first generation mobile phone (King and West, 2002; Lyytinen and Fomin, 2002; Lehenkari and Miettinen, 2002), second generation mobile phone (Haug, 2002; Bekkers et al, 2002; Funk, 2003), overall mobile phone (Garrard, 1998; Funk and Methe, 2001; Funk, 2002), and mobile Internet (Fransman, 2002; Natsuno, 2003; Sigurdson, 2001) standard setting. Due to the high rate of recent change in the mobile Internet, we also supplemented the published sources with consulting reports and interviews with the largest service providers, technology providers, and phone manufacturers in the world.

Between 2001 and 2005, multiple interviews were conducted with multiple managers of NTT DoCoMo, KDDI, Vodafone, T-Mobile, Hutchison Telecom, Sprint, Cingular Wireless, Nokia, Ericsson, and Qualcomm Japan, and Qualcomm Korea. Because these interviews revealed that the failure of the global standard setting process for mobile Internet standards, WAP (Wireless Automation Protocol), had forced individual service providers to define their own mobile Internet specifications and have custom phones made according to these specifications (Economist, 2005; Reinhardt and Ihlwan, 2005), we focused our recent interviews on the largest service providers in the world and also investigated the history of their services via press releases on their sites.

4. Results: A brief history of standard setting in the mobile phone industry

Following Durham (1991), Table 1 defines the general categories of an evolutionary process for standard setting in the mobile phone industry. The unit of transmission is the method of standard setting and the sources of variation are different countries with different methods of standard setting. In the process of transformation, governments and firms have adopted new forms of standard setting for a variety of reasons including to promote domestic growth and domestic equipment producers. Government agencies, multi-national firms, and organizations act as the mechanisms of transmission. Sources of isolation include language, culture, and government policies.

Table 2 summarizes technological change in the wireline and mobile phone industries and its impact on problem solving, the dominant form of standard setting, competition policy, and industry structure. Within wireline, it differentiates between pre- and post-deregulation and within mobile phones, it differentiates between three generations of air-interface standards and the mobile Internet. Table 3 provides more details on the interaction between technological change and the evolution of standard setting where the table differentiates between the setting of the air-interface standards and the determination of phone specifications. Table 4 lists the most widely used air-interface standards.

Partly driven by changes in the wireline industry, there was an evolution towards more open standard setting in the first three generations of mobile phone air-interface standards. The U.S. and Scandinavia moved the fastest followed by the rest of Europe and Japan (See Figure 1 and Table 3). As graphically represented in Figure 2, the faster growth in those markets that adopted more open forms of standard setting and competition encouraged other countries to also introduce open standards and competition. The diffusion of open standard setting and competition also caused research and development to move from away from service providers and towards manufacturers and other firms (change in industry structure), which strengthened the open standard setting processes and patent protection. It has only been in the latest generation of technological change (the mobile Internet) that the dominant form of standard setting has come full circle and returned to its original form of quasi-vertical integration due to the need for integral problem solving.

Place Tables 1-4 and Figures 1 and 2 about here

4.1 Wireline

Until the 1980s, telecommunication industries in most advanced countries were in a state of quasi-vertical integration. Regulated monopolies argued that the possibilities of harm to the network from the attachment of unauthorized equipment required them to be responsible for determining all the specifications in a wireline system from switching equipment to phones (Brock, 1981; Brock, 1994; David and Steinmueller, 1994). In this integral problem solving the regulated monopolies ordered equipment often from single vendors where the same phones, usually black ones, were used by almost everyone in a single country. It was only in less advanced countries that service providers purchased turnkey systems from vendors and thus there was greater competition between equipment vendors than there was in advanced countries (Fransman, 2002).

There was a slow move towards modular problem in the second half of the 20th century that accelerated in the 1970s and 1980s as firms and governments began to realize that service providers did not need to be responsible for defining all the specifications in a telephone system (Fransman, 2002). From the technological side, the move to modular problem solving was driven by the use of electronic switches, which reduced the “coupling” between the phones and switches (Talley, 1982; David and Steinmueller, 1994; Steinmuller, 2003) partly because the electronic switches handled the speech and signaling paths separately. Although electronic switching was first introduced in the 1960s (Huurdeman, 2003), the implementation of modular design also required regulatory changes that came about in the U.S. through a number of court cases in the 1950s, 1960s, and 1970s where the lack of harm to the network from each change gradually convinced the Federal Communications Commission (FCC) and other parties that a fully open interface in which phones were attached to network via standard plugs as opposed to hard wiring would be beneficial to consumers. It became possible for consumers in 1978 to purchase phones from manufacturers other than AT&T's manufacturing subsidiary Western Electric where these manufacturers were free to determine the specifications and designs for phones in any way they liked as long as the phones conformed to the open interface (Brock, 1981, 1994). The definition of this open interface also supported the Justice Department's breakup of AT&T that enabled competition between service providers to increase in the early 1980s. Other large advanced countries such as Great Britain, France, and Germany followed with similar changes in the mid-to late 1980s (Fransman, 2002).

4.2 Analog Mobile

The different rates at which countries defined an open interfaces between phones and networks and deregulated their wireline industries was the primary source of variation in the method of standard setting in analog mobile systems. Just as the U.S. and Scandinavia ones were the first countries to define open interfaces between the phone and network in the wireline industries, they were also the first countries to do so in analog mobile systems (Funk and Methe, 2001, Lyytinen and Fomin, 2002). In the U.S., the FCC was the primary mechanism of transmission while the overall driver of change was the Justice Department. The FCC had learned from its experience in the wireline industry that modular problem solving was both possible and advantageous to consumers and based on proposals from manufacturers it defined an open interface for an "Advanced Mobile Phone System" (AMPS) and published specifications for the interface (Lyytinen and Fomin, 2002). The definition of this open interface coincided with the breakup of AT&T, which was a result of a ten-year court battle with the Justice Department. As it defined the open interface, the FCC also divided the U.S. into more than 700 regions and awarded licenses to two firms in each of them in a complex drawn out process (Garrard, 1998; King and West, 2002).

In Scandinavia, it was both competition with non-Scandinavian countries and cooperation with other Scandinavian countries that encouraged the service providers and regulatory agencies to implement open standard setting processes and modular problem solving (Fransman, 2002). National service providers began defining interfaces between the wireline network and phones and other key building blocks within the network and ordering equipment from multiple vendors in the 1960s. These national service providers also cooperated on the creation of a pre-cellular[1] and later on an analog cellular mobile phone system that was called the Nordic Mobile Telephone (NMT) system (Lehenkari and Miettinen, 2002; Lyytinen and Fomin, 2002). Using the terminology of evolutionary processes, regulatory agencies and service providers were the means by which the open method of standard setting was transmitted (mechanism of transmission) from wireline to pre-cellular and cellular systems (Fransman, 2002). Although competition between mobile phone service providers within Scandinavia was not introduced until digital services (see below) were started in the early 1990s, users

[1] Pre-cellular systems used a single transmitter to cover a large area.

were allowed to purchase phones and thus there was competition between phone manufacturers (Hulten and Molleryd, 1995; Lehenkari and Miettinen, 2002).

Scandinavian countries began introducing analog mobile phone services based on NMT in 1981 and the U.S. based on AMPS in 1983. While other advanced countries such as Japan, Germany, France, and Italy also introduced their own unique systems, there was little growth in their systems due to the lack of open standards, the control of these standards by the national service providers, and a lack of competition between either service providers or between manufacturers all of which reflected a continuation of quasi-vertical integration by the national service providers. By the end of 1986, more than 80% of the world's subscribers used phones that were based on NMT, AMPS, or a variant of AMPS and most of these subscribers were either in North America, Scandinavia, or Great Britain (Garrard, 1998; Funk, 2002).

4.3. Digital Mobile

The greater success of the Scandinavian and U.S. mobile phone markets encouraged other countries to introduce open standard setting processes and modular problem solving for digital systems (See Figure 1 and Table 2). Germany and France, which had previously tried to convince Great Britain to develop an alternative to the U.S. and Scandinavian analog systems, had turned their attention to digital systems by 1984 (Funk, 2002) and the creation of an open system that would later become a global standard. Using a committee called Group Special Mobile that had been created in 1982 by the Conference Posts and Telecommunications (CEPT), Germany and France created an alliance of Western European governments, service providers, and later manufacturers that developed the GSM standard, whose name was later to become

Global System Mobile. By early 1987, 15 countries had signed a memorandum of understanding (MOU) to introduce digital systems that were based on the GSM standard (Meurling and Jeans, 1994; Garrard, 1998).

Scandinavian government agencies and to a lesser extent service providers and manufacturers such as Ericsson and Nokia acted as the mechanisms of "transmission" of this open approach to standard setting in Western Europe. These government agencies and firms convinced Germany, France, and other European countries to adopt Scandinavia's open form of standard setting in which service providers initially played the key role (Haug, 2002). The service providers in CEPT evaluated a number of proposals from manufacturers and chose a basic design in 1987 (Meurling and Jeans, 1994; Garrard, 1998; Haug, 2002) where a growing desire for economic integration within Western Europe and competition with the U.S. and Japan also helped convince European countries to cooperate with each other (Funk and Methe, 2001; Funk, 2002).

It was only with the creation of ETSI (European Telecommunications Standards Institute) that manufacturers began to become the dominant players in standard setting for GSM and thus the mobile phone industry. The standard setting work for GSM was transferred from the CEPT to ETSI in January 1988 where a key decision by ETSI was to use subscriber information module (SIM) cards, which enabled a phone to be used with any GSM service provider merely by exchanging the SIM cards (Hawkins, 1993; Garrard, 1998) thus further strengthening modular problem solving

The transfer of standard setting to ETSI and the use of SIM cards reflected the increasing power of the manufacturers and also contributed to it (See Figure 2). During the 1980s, manufacturers had been steadily increasing their development spending in the wireline and mobile industries while service providers had been reducing their spending (Fransman, 2002). The manufacturers achieved a major victory in GSM when the service providers revoked their claim for a common IPR (Intellectual Property Rights) policy in the late 1980s (Bekkers et al, 2002). Stronger patent protection further strengthened the role of manufacturers in both development and standard setting in GSM and helped them become global agents of diffusion for the GSM standard (Funk and Methe, 2001).

Countries that did not adopt GSM as a national standard include the U.S., Japan, and Korea. The U.S. extended its concept of competition from that between service providers and manufacturers to that between standards (See Figure 1) and it auctioned the frequency spectrum as opposed to awarding the spectrum on the basis of a "beauty contest" (Garrard, 1998; Scanlon, 2001). Following the auctions, services were started in the U.S. that were based on several standards including GSM, TDMA, and CDMA (Scanlan, 2001) where CDMA was based on Quallcom's technology. Although there are many versions of Quallcom's CDMA technology, this paper calls Quallcom's 2nd generation technology cdmaOne and its 3rd generation technology cdma2000.

Korea and Japan also did not adopt GSM as a national standard and thus both countries and in particular Japan continued their isolation in an evolutionary sense. Korea adopted cdmaOne as its digital standard in the mid-1990s while Japan allowed its major service provider, NTT DoCoMo to define the national standards for analog and initially digital systems (Funk, 2002; Funk, 2003).

The common aspect of Japan and Korea's isolation was that they did not use GSM and SIM cards. This slowed the introduction of global roaming, the complete introduction of modular problem solving between phones and services, and the movement of development spending from service providers to manufacturers. Service providers continued to define the specifications for phones (Funk, 2003), which can be seen as a partial continuation of quasi-vertical integration (See Table 3). Unlike the West where open standards and SIM cards had completely destroyed quasi-vertical integration, it has continued to partially exist in Japan and Korea. As shall be described in section 4.5, the Japanese and Korean service providers have used their ability to define phone specifications and standards for mobile Internet services to ensure the consistent display of content across different phones (See Table 3).

4.4. Third Generation

The success of GSM further strengthened the policies of openness, modular problem solving, competition, manufacturer development, and patent protection in the third generation standard setting process. By the end of the 1990s, the GSM Alliance had become a global organization with a global standard setting process that was integrated with the processes of the International Telephone Union (ITU). Qualcomm's desire to promote its version of CDMA called cdmaOne and to compete with the GSM standard caused it to form the CDMA Development Group, which also became integrated with the ITU and now plays the same role as the GSM alliance does (Funk, 2002). Here it was both manufacturers and service providers that were the mechanisms for the transmission of open standard setting from the GSM Alliance to the CDMA Development Group.

Governments also increased the amount of competition by increasing the number of licenses and awarding them via auctions as opposed to "beauty contests." By the late 1990s, many countries had awarded third generation licenses via these auctions (See Table 2) some of which commanded more than 50 Billion Euros (BBC, 2000). By the early 2000s the number of countries announcing their plans to liberalize the choice of air-interface standard (including Europe) had also increased (Scanlan, 2001; Economist, 2000).

Outside of Japan, manufacturers did most of the development work and patents played an even larger role in third generation than in second generation standard setting. Qualcomm's large number of patents in CDMA and its decision not to offer mobile phone infrastructure or handsets (it initially entered and withdrew) further increased the importance of patents where there were major conflicts between Qualcomm and the traditional manufacturers like Ericsson and Nokia in the late 1990s and early 2000s[2].

The success of GSM also finally had an impact on standard setting in Japan thus breaking down the walls of its isolation (in the evolutionary sense) in the late 1990s. Differences in language and culture and the fact that the Japanese government allowed NTT DoCoMo to control the analog and digital phone standard setting processes were some of the reasons for Japan's previous isolation. Domestic and foreign manufacturers and service providers worked to end this isolation and this sense they can be seen as one of the mechanisms of transmission of an open approach in third generation standard setting in Japan. Domestic manufacturers felt that Japan's adoption of proprietary systems in analog and digital systems had isolated them from the global market while other Japanese service providers complained about NTT DoCoMo's domination of domestic standard setting. Foreign manufacturers such as Motorola, Nokia, and Ericsson and service providers such as Vodafone also pushed for more openness in order to facilitate their participation in the Japanese market. These complaints caused the Japanese government to demand in the mid-1990s that NTT DoCoMo either adopt or

[2] For example, see (WSJ, 1998).

create a global standard for third generation systems (Funk and Methe, 2001; Funk, 2002) and to approve the use of a non-Japanese second generation digital system (cdmaOne), which Japan's second largest service provider (KDDI) adopted.

As they had done in second generation standard setting, Scandinavian organizations, albeit here it was Ericsson and Nokia, were an additional mechanism of transmission of a new approach to standard setting for Japan. NTT DoCoMo had chosen to create a global standard with its W-CDMA (Wide-Band CDMA) technology and Ericsson and Nokia agreed to support W-CDMA in exchange for having the GSM network interface included in the global standard. They did this partly because there was a growing consensus in the late 1990s that Qualcomm's cdmaOne technology was technologically superior to GSM and might be chosen as a third generation standard by Europe. This was a major threat to Nokia and Ericsson since they were not supplying any cdmaOne infrastructure (Funk and Methe, 2001; Funk, 2002). Ericsson and Nokia used this concession concerning the network interface to convince European service providers to adopt W-CDMA in ETSI in January 1998. Subsequently most service providers that use GSM have introduced W-CDMA while the initial adopters of cdmaOne have introduced cdma2000 and its improved versions.

4.5. Mobile Internet

The success of open air-interface standards and the setting of them by manufacturers in the first three generations of mobile phone systems initially strengthened the policies of openness and manufacturer development in standard setting for the mobile Internet. Nokia, Motorola, and Ericsson acted as the mechanisms of transmission in an evolutionary sense in that they created the WAP (Wireless Application Protocol) Forum in June 1997. There were almost 100 members by early 1999 and more than 500 by mid-2001 (Sigurdson, 2001).

However, in spite of the emphasis on openness, the manufacturers were unable to agree on standards in the mobile Internet. The lack of agreement on standards led to an inconsistent display of menus and content across different phones and it required users to configure the services themselves; both of these problems substantially reduced interest in the services (Sigurdson, 2001; Fransman, 2002). Furthermore, the ability to use GSM phones in every country, which is a major advantage in voice applications, became a disadvantage as every GSM service in the world experienced the same problems with phones.

On the other hand, Japanese and Korean service providers continued to define phone specifications and maintain a partial system of quasi-vertical integration (See Table 3). In Japan, NTT DoCoMo defined its own mobile Internet standards, had manufacturers develop phones that conformed to these standards, and introduced i-mode in February 1999 (Fransman, 2002; Natsuno, 2003). The success of i-mode caused other Japanese and Korean service providers to introduce similar services in 1999 and 2000. Japan's second and third largest service (KDDI and J-Phone) and Korean's three largest service providers (SK Telecom, KT Freetel, and LG) also define their own standards and have manufacturers supply them with phones that are customized for their mobile Internet services.

The difference in performance between Japan, Korea, and the rest of the world reflects changes in the appropriate method of problem solving and thus the need for a different method of standard setting (See Table 2). While the Western approaches to standard setting worked well with modular problem solving, the mobile Internet requires integral problem solving. As opposed to the single air-interface standard that was handled with an open standard setting process, there are multiple interfaces in the mobile Internet where each interface involves a different application and the importance of an application must be recognized before a standard can be set for the application. It is well recognized that individual firms can identify these market opportunities better than standard setting committees (Shapiro and Varian, 1999) and this was certainly the case in the mobile Internet. Initially the WAP Forum did not even try to define standards for entertainment applications such as ringing tones, screen savers, and games, which have become the killer applications in the mobile Internet.

Furthermore, consistency between the multiple interface standards is needed and this consistency must be maintained as changes in technology require updates to the multiple standards. For example, each type of entertainment content requires a specific method of formatting ringing tones, screen savers, and games, these formats must be consistent with other phone software such as browsers, Java virtual machines, mail/messaging clients, and packet and micro-payment systems[3], and these formats and other software are updated as improvements in displays, processors, and other chips are implemented. Maintaining the consistency between multiple interface standards requires integral problem solving by service providers.

Although the process of change is still underway, the greater success of the Japanese and Korean service providers has caused Western service providers to also define phone specifications, order custom phones, and thus reintroduce a partial form of quasi-vertical integration. In an evolutionary sense, the mechanisms of transmission are

[3] In the micro-payment systems, service providers bill the users for purchases of content and give a percentage of these fees to the content providers.

service providers such as NTT DoCoMo and Vodafone and Japanese and Korean phone manufacturers. NTT DoCoMo has licensed its i-mode service to more than 10 non-Japanese service providers. Vodafone has used its investment in Japan's third largest service provider, J-Phone (called Vodafone Japan until Softbank acquired it in 2006) to understand the necessary specifications for the mobile Internet and introduce a global service called Vodaphone Live!. Korean and Japanese phone manufacturers were the first ones to offer custom phones to Vodafone and other Western service providers such as Sprint PCS, Hutchison Telecom, and Verizon Wireless where Nokia and Motorola did not supply these custom phones in large volumes until 2004 (Economist, 2005; Reinhardt and Ihlwan, 2005).

This change in standard setting has put the West significantly far behind Japan and Korea in the mobile Internet (Natsuno, 2003). Vodafone did not introduce its mobile Internet service, Vodafone Live! until more than 3/12 years after NTT DoCoMo introduced i-mode and other Western service providers have been much slower to set specifications and obtain custom phones. Furthermore, several key aspects of the NTT DoCoMo's i-mode service such as Internet mail on all phones have not been introduced outside of Japan. Instead, SMS is still the dominant form of messaging service outside of Japan and the prices for SMS are 5-15 times the price in Europe and the U.S. as the prices for mobile mail are in Japan[4].

Nevertheless, a convergence in standard setting in the mobile Internet is occurring

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[4] NTT DoCoMo charges 1 Yen (0.008 Euros at 125 Yen per Euro) to receive a short Internet mail message (http://www.nttdocomo.co.jp/english/p_s/charges/mova/f/imode.html) versus 0.136 Euros to receive an SMS in Europe (Credit Suisse, 2004). Other service providers do not charge users to receive Internet mail in some plans (e.g., Vodafone Japan). http://www.vodafone.jp/english/live/mail/skymail.html

and standard setting in the mobile Internet now partially resembles that of the wireline industry in the late 1970s. Just as the service providers in the largest countries were able to determine the specifications and obtain custom equipment for their wireline systems more than smaller countries were able to do in the late 1970s (Fransman, 2002), the largest mobile phone service providers can now obtain custom phones much easier than smaller ones can, which place the smaller service providers at a large disadvantage. On the other hand, as mobile Internet services evolve and mature, it is likely that an open interface or a dominant design (Abernathy and Utterback, 1978; Anderson and Tushman, 1990; Utterback, 1994) will emerge between the phones and networks that will enable a return to modular problem solving.

The major difference between the wireline industry in the late 1970s and the mobile Internet in 2005 is that the large service providers are now global and not national providers and they order their phones from global and not national manufacturers. This is most evident in Europe where a few global players offer most of the mobile phone services. The competition between mobile Internet services is now between global service providers who are trying to convince global manufacturers to make custom phones for them. And unlike the late 1970s, national governments have far less power to influence this competition. Time and further research will tell us about the merits and demerits of this case of "globalization."

5. Discussion

The goal of this paper was to explore the co-evolution of technology, institutions, and industry structure in the mobile phone industry with a focus on technological change and the institution/method of standard setting. This paper finds that the methods of standard setting have lagged changes in the method of problem solving that were brought about by technological change. Initially, different countries with different methods of standard setting were the sources of variation in this co-evolutionary process. Standard setting processes that led to growth in specific countries were adopted by other countries in the next generation of technology where government agencies, multi-national firms, and organizations acted as the mechanisms of transmission of these standard setting processes.

The most interesting aspect of this co-evolution of technology and standard setting is its circular nature. During the 1960s, 1970s, and 1980s some firms and governments began to recognize that it was possible to create an open interface between phones and networks in wireline and later mobile phone systems and thus use modular in place of integral problem solving. The move from first to second and third generation mobile phone systems strengthened this modular problem solving and the open standard setting processes that supported it. However, the mobile Internet has changed the method of problem solving from modular to integral and this has caused the method of standard setting to return to a situation that is partly similar to one that existed for wireline in the late 1970s. The mobile Internet now requires integral problem solving as opposed to the modular problem solving needed for setting air-interface standards. This has caused the quasi-vertical integration of Japanese and Korean service providers to work better than the "open" standard setting processes of WAP where the existence of the WAP Forum and the support by manufacturers for it act as a "core rigidity" (Leonard-Barton, 1992).

We can also think of this change in standard setting as a change in physical and social routines. Air-interface standards can be thought of as a collection of physical routines for physically transmitting signals between a single interface that connects mobile phones and base stations. On the other hand, mobile Internet standards can be thought of as physical routines that involve *multiple* interfaces between phones, servers (i.e., content providers), and services (i.e., service providers) where each interface involves a different application and the important entertainment applications were not initially recognized. Both the identification of these applications and the setting of standards for them require a different set of social routines than are needed for the determination of the air-interface standards.

The social routines of standard setting have been transmitted by firms and government agencies. In the second and third generation systems, Scandinavian government agencies and firms (Ericsson and Nokia) were major transmitters of these social routines from their successful first generation standard setting processes and this may be one reason why Ericsson and Nokia still remain the leading suppliers of infrastructure and phones respectively. It is too early to forecast how recent changes in standard setting in the mobile Internet will impact on these firms. While it appears that the change in problem solving and thus the appropriate method of standard setting favor service providers such as NTT DoCoMo and Korean manufacturers like Samsung, it is possible that the integral problem solving is merely a temporary situation until a dominant design (Anderson and Tushman, 1990) emerges as it did for example in the personal computer (PC) industry where vertically integrated solutions gave way to modular ones following the introduction of the IBM PC (Langlois, 1993).

In addition to the co-evolution of technology and standard setting, this paper has also touched on the co-evolution of competition and patent policy and industry structure. Open standard setting facilitated the introduction of competition in phones and services and led to growth in mobile phone markets first in Scandinavia and the U.S. This growth led to further support for open standard setting and competition in these and other mobile phone markets (See Figure 2). By the early 1990s, most countries had introduced competition in mobile phone services and these services were based on open standards and open standard setting processes. Increased openness in the standard setting process also reflected a move in development activities from service providers to manufacturers where increasing returns to development (Klepper, 1996) and stronger patent protection probably accelerated this move. The greater openness in the standard setting processes used in Western markets caused this to happen faster in the West than in Japan and Korea. The slower move to open standards in Japan and to a lesser extent Korea caused NTT DoCoMo and to a lesser extent other Japanese and Korean service providers to retain their development capability and exert more control over the phone specifications.

Future research should consider the co-evolution of technology and standard setting in other industries. The increasing number of industries that require standards, the growing number of standard setting institutions, and the large variety in these institutions suggest that this is a fruitful area of research. Industries such as computers, music, and broadcasting have experienced large amounts of change in both technology and the method of standard setting and it is likely that there has been an interaction between them. Such research will likely shed more light on the process of co-evolution.

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Table 1. Application of Durham's (1991) Categories to the Mobile Phone Industry

General Category	In Mobile Phone Industry
Unit of transmission	Method of standard setting
Sources of variation	Different countries and different histories
Mechanisms of transmission	Government agencies, multi-national firms, and standard setting institutions
Processes of transformation	Governments and firms adopt new routines in their standard setting processes to promote domestic growth and equipment suppliers
Sources of isolation	Language, culture, geography, firm and government policies

Source: author's analysis

Table 2. Evolution of Technology, Institutions, and Industry Structure (Leading Forms) in Telecommunications

Fixed versus Mobile	Dates	Generation/ Era	Method of Problem Solving	Institutions		Industry Structure: Development Spending by
				Standard setting	Competition Policy	
Fixed	Until early 1980s	Regulated	Integral problem solving	Quasi vertical integration	Monopoly	Service Provider
	After mid 1980s	Deregulated	Modular problem Solving	Open standard setting at national level	Multiple licenses	Manufacturer
Mobile	1970s and 1980s	First generation: analog	"	"	Some multiple licenses	Manufacturer
	1980s and early 1990s	Second generation: digital	"	Open standard setting at trans-national level	Multiple licenses with some auctions	Manufacturer
	Late 1990s	Third generation	"	Open standard setting at global level	Multiple licenses with more auctions	Manufacturer
	2000s	Mobile Internet	Integral problem solving	Quasi vertical integration	No effect	Service Provider?

Source: Adapted from (Brock, 1981; Fransman, 2002; Funk, 2002; Lyytinen and Fomin, 2002)

Table 3. Technological Change and Evolution of Standard Setting Approaches

Technological Generation	Determination of Interface Between Network and Phone	Determination of Phone Specifications
Fixed Wireline	Service providers determined everything until early 1980s	
First generation mobile (analog)	Open process introduced in US and Scandinavia	Phone manufacturers in US and Scandinavia
Second generation mobile (digital)	Open process expanded to all parts of Europe and many parts of Asia	Phone manufacturers in most of the world (except Japan and Korea)
Third generation mobile	Open process expanded to most parts of the world and dominated by manufacturers	"
Mobile Internet	In transition: failure of WAP Forum caused Western service providers to copy Japanese and Korean methods of determining phone specifications and other interface standards	

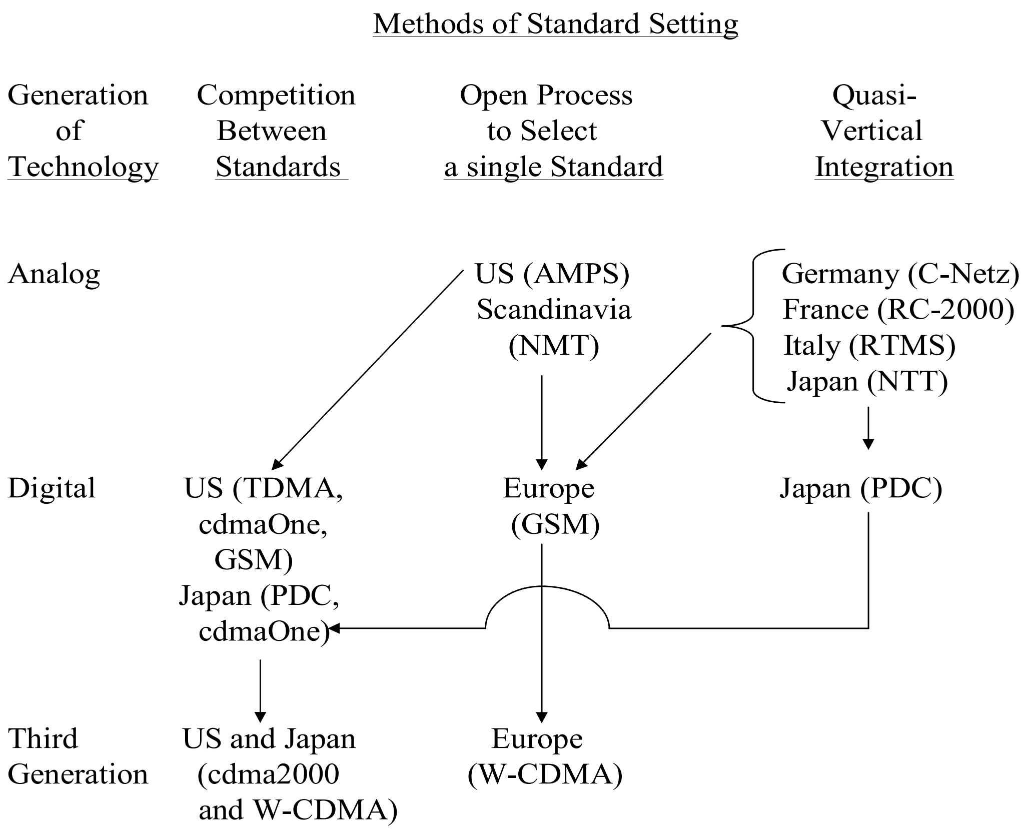
Source: Adapted from (Brock, 1981; Fransman, 2002; Funk, 2002; Lyytinen and Fomin, 2002)

Table 4. Most Widely Used Air-Interface Standards

Generation of Technology	Communication Standard	Origin of Standard	Year in which Services were first started
1st Generation Analog Cellular	NMT (Nordic Mobile Telephone) AMPS (Advanced Mobile Phone System)	Scandinavia North America	1981 1983
2nd Generation Digital Cellular	GSM (Global System Mobile) TDMA (Time Division Multiple Access) PDC (Personal Digital Cellular) cdma (Code Division Multiple Access) One	Europe U.S. Japan Qualcomm	1992 1992 1993 1994
3rd Generation Digital Cellular	Wide-Band CDMA cdma2000	Global Global	2001 2001

Sources: (Garrard, 1998; Funk and Methe, 2001; Funk, 2002; Lyytinen and 2002)

Figure 1. Evolution of Standard Setting Methods in Major Countries
(Standards are in parentheses and arrows show evolution both within and between generations)



Sources: (Funk and Methe, 2001; Funk, 2002; Lyytinen and Fomin, 2002; and author's analysis)
Abbreviations: NMT (Nordic Mobile Telephone); AMPS (Advanced Mobile Phone System); NTT: Nippon Telephone and Telegraph; GSM: Global System Mobile; TDMA (Time Division Multiple Access); PDC (Personal Digital Cellular); cdma (Code Division Multiple Access); W-CDMA: Wide-Band cdma

Figure 2. Positive Feedback Between Market Growth, Manufacturer Development, and Support for Openness, Competition, and Patent Protection