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# The Paradox of Standard Flexibility: The Effects of Co-evolution between Standard and Interorganizational Network

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**Abstract**
The literature has dedicated significant attention to the effects of standard-supporting, interorganizational networks on the content of standards and standard survival. However, minimal attention has been paid to the effects of the standard's characteristics and dynamics on these networks. This paper contributes to closing this gap. We introduce the paradoxical concept of 'standard flexibility' and study the interaction between the characteristics of a standard-supporting network and the development of the standard itself, including the effect of the interaction on standard success. More specifically, we show how a standard's flexibility can serve to attract new network members, facilitating growth and diversity of the network, which in turn has implications for further adaptations of the standard. We study this co-evolutionary process in three standards battles: Blu-ray versus HD-DVD, USB versus Firewire, and WiFi versus HomeRF. Our findings suggest that those participating in standardization can persuade non-participating stakeholders to join by allowing for changes in the standard. In turn, the existing members can expect that the new members will request further changes. The cases suggest that early timing of the co-evolutionary process enhances the chances of standard success. We also explore the emergence of path dependencies in the process and the forces that restrict the co-evolutionary process over time. For managers, our findings indicate that

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changes in standards should not be considered undesirable, but as opportunities that may strengthen the interorganizational network and contribute to a standard's success.

**Keywords**
co-evolution, interorganizational networks, path dependency, standardization

## Introduction

Several authors have studied the effects of networks of standard-supporting organizations on the success of standards (Keil, 2002; Markus, Steinfield, Wigand, & Minton, 2006). They showed the influence of network characteristics, such as the size of the network in standardization committees (Egyedi, 1996; Fomin, 2001; Schmidt & Werle, 1998) or industry consortia (Weiss & Cargill, 1992) and the diversity of actors (Gomes-Casseras, 1994) on the chances that a standard achieves dominance. Some authors go a step further and study the antecedents of the formation of standard-setting alliances (Axelrod, Mitchell, Thomas, Bennett, & Bruderer, 1995; Vanhaverbeke & Noorderhaven, 2001). However, authors have, thus far, treated the standard itself as exogenous to network formation. In other words, the literature has studied how the network of standard supporters affected standard success, but considers the standard itself as an effect of the network members' actions and not as an endogenous element in the formation of the network.

In this paper, we study the reciprocal relation between standard flexibility and interorganizational network formation. We focus on compatibility standards, defined as 'codified specifications defining the interrelations between entities in order to enable them to function together' (based on De Vries, 1999; Garud & Kumaraswamy, 1993). Standard flexibility refers to the number and degree of changes to a standard over time. The concept of standard flexibility is paradoxical since standards aim at creating sustained compatibility between different technologies, and therefore stability in markets, while flexibility creates instability. However, we show that flexibility of standards can promote support by a network of supporters and thereby stability in the longer term. In particular, we propose that, on the one hand standard flexibility can enhance both network diversity and size, and on the other hand the diversity of standard-supporting networks will have further effects on standard flexibility. Through an exploratory study of three cases of compatibility standards, we examine the specifics of the co-evolutionary process resulting from this reciprocal relationship over time and show its effects on standard success. In addition, by investigating the emergence of path dependencies in the process, we explore the forces that restrict the process over time.

By studying the reciprocal relationship between network characteristics and network outcomes, we contribute not only to the standardization literature, but also to the social network literature in general. In this literature, there is widespread recognition that social networks are important for the performance of individuals, firms and even regions (e.g. Borgatti and Foster, 2003; Burt, 1992; Granovetter, 2005). There has also been some attention to the antecedents of networks (Brass, Galaskiewicz, Greve, & Tsai, 2004; Nebus, 2006). However, in part due to the limited availability of longitudinal network studies (Elfring & Hulsink, 2007; Streier & Greenwood, 2000; Zaheer & Soda, 2009), the effects of network outcomes on the dynamics of the network itself have hardly been addressed (Perry-Smith & Shalley, 2003). Exceptions are Autry and Golicic's (2010) study on buyer–supplier relations and Lee's (2010) study on patent networks. Our study contributes to this research by investigating a so far unaddressed issue: the effects of the interaction between changes in network outcomes (standard flexibility) and network characteristics (size and diversity) on (standard) success.

The paper proceeds as follows. First we explain our theory on the relation between networks of organizations supporting standards and standard flexibility. We also address the issue of path dependency in standardization processes. We then present our methodology and the three case studies of standards battles, each followed by a short analysis. This is followed by a cross-case analysis. In the discussion and conclusion section we summarize our findings and relate these to existing literature. We also address the practical implications of our study. Finally, we set out paths for future research.

## Networks and Standard Performance

Standardization literature has pointed to several characteristics of interorganizational networks affecting the success chances of standards. The seminal paper of Cusumano, Myonadis and Rosenbloom (1992) on standard competition in the video recorder industry shows that the size of the interorganizational network was an important determinant in the success of VHS over competitors such as Betamax and V2000. The VHS network included more stakeholders from the core industries, consumer electronics and film studios, and this stakeholder network was built earlier. Other authors studied the effect of a firm's position in a network on the firm's influence in standard-setting (Leiponen, 2008) and the role of networks of individuals for the firm's influence in standards setting (Dokko & Rosenkopf, 2010).

In accordance with general literature on social and interorganizational networks (Burt, 1992; Coleman, 1990; Provan, Fish, & Sydow, 2007), standardization literature on interorganizational networks emphasizes the benefits of networks for collective action and coordination of tasks. Inter alia, it shows that coordinated action is required in the interorganizational network behind a standard, in order to develop a joint marketing strategy, such as a market penetration strategy (Ehrhardt, 2004), and to spend sufficient resources on marketing the standard (Schilling, 1999). Collective action can also refer to strategic marketing communications (pre-announcements) which discourage users from adopting rivals' standards (Besen & Farrell, 1994; Shapiro & Varian, 1999), or to a collective licensing strategy with respect to the standard (Bekkers, Duysters, & Verspagen, 2002; Clarke, 2004; Marasco & Dodson, 2004; Merges, Menell, & Lemley, 2004).

The general network literature shows the importance of networks for information exchange, particularly diverse information (Burt, 1992; Campbell, Marsden, & Hurlbert, 1986; Coleman, 1990; Granovetter, 1973). The notion that diverse information, if combined, can lead to new knowledge is deeply rooted in the literature on innovation (Allen, 1977). Information and coordinated action are mutually reinforcing and cumulative over time (Burt, 1997). Also in the standardization literature, information exchange between actors with diverse backgrounds is considered important, particularly in the early phase of the development of a standard (De Vries, 1999; Markus et al., 2006; Susanto, 1988). Diversity of participants in standards development shapes the contents of the standards, and improves performance (Beckman & Haunschild, 2002; Egyedi, 1996; Schmidt & Werle, 1998). Involvement of stakeholders will likely result in a standard with a content that reflects their specific needs (Markus et al., 2006). Evans, Meek and Walker (1993) and Lundval (1995) show this in the case of user involvement in standardization. On the other hand, diversity can entail challenges for decision-making. Cargill (1997, p. 233) suggests that the key to successful standardization is managing the diversity of the participants; in turn, their input leads to a standard's content that meets the needs of the sectors represented by the stakeholder. Deliberation processes resulting in consensus can be extremely important (Scherer & Palazzo, 2007), but the more participants, the more difficult it is to achieve consensus (Rada, 2000; Vercoulen & Van Wegberg, 1998) leading to delay.

A third benefit of networks refers to their role in creating status and legitimacy (Podolny, 1993). The reputations of firms in standard-supporting networks with respect to successful standard-setting in the past are important in creating future prospects for customers and other parties (Axelrod et al., 1995). A group of standard supporters with a good reputation will also find it easier to attract new members to join the group (Foray, 1994). The standardization literature has also shown that the involvement of a broad variety of stakeholders may contribute to the legitimacy of the standard development process and the resulting standards (Lundval, 1995; Scharf, 1999), thus yielding a higher likelihood of market acceptance.

In this paper we focus on the role of interorganizational networks for information exchange and coordinated action. Information can provide actors with opportunities, and coordinated action can provide the cooperative behaviour needed to explore those opportunities (Podolny & Baron, 1997). Of course, when collective action leads to an extension of the network of standard supporters, the legitimacy of the network is often also strengthened. While the standardization literature emphasizes the importance of information exchange between actors in the early phase of the life of a standard, in this paper we extend the role of information exchange to later phases. We expect that diverse network members can use their repositories of knowledge and the experience acquired in the standard diffusion process to define the future direction of the standard. Subsequently, collective action serves to adapt the standard to current and expected future requirements, particularly to the requirements from different industries and consumer groups. The modification of the standard will attract network members from those new industries, further increasing the diversity and size of the network. Information exchange in the network can subsequently lead to new adaptations of the standard to suit both current and prospective network members.

The topic of standard flexibility has been addressed by Egyedi and Blind (2008), who speak of ‘standards dynamics’, referring to ‘the changes to and interactions between standards, that is, what happens to standards once they have been set’ (p. 4). While they use the term standard dynamics to include local changes in the standards by specific implementers, and the succession between standards, we use the term standard flexibility for changes in a standard’s contents over time. While Egyedi and Blind (2008) emphasize the replacement of standards, and thus a selection perspective, we apply an adaptation perspective, emphasizing the abilities of standard-supporting networks to change the standard as well as the network over time (Hodgson, 2001; Lewin & Volberda, 1999).

Since we study the joint dynamics of standards and their supporting networks, we include in our analysis the processes that create path dependencies in the evolution of a standard. The evolutionary economics literature has extensively shown how so-called network effects may lead to path dependencies in the development of products and markets. These network effects occur as a consequence of the installed base (direct network effects) of a standard and the availability of complementary products (indirect network effects) (Adler, 1992; Farrell & Saloner, 1986; Van den Ende & Wijnberg, 2003). Network effects lead to self-reinforcing processes, resulting in path dependencies and sometimes in a winner-takes-all situation. Actors become locked in to a single standard, unless switching costs are very low (Shy, 2001). A classic and well-known example of lock-in is the QWERTY keyboard. Existing skills of typists reinforce the dominance of a keyboard layout geared to the needs of mechanical typewriters (David, 1985). However, network effects do not always lead to a single outcome. For instance, in the case of video game consoles (Schilling, 2003) and flash memory cards (De Vries, De Ruijter, & Argam, 2011) multiple standards remained to co-exist.

In this paper, we investigate how the reciprocal process between a standard’s support network and standard flexibility contributes to network effects and path dependencies. For instance, the network of standard supporters may contribute to the installed base and availability of complementary products, and thus enhance both direct and indirect network effects. On the other hand, standard-supporting networks themselves represent a certain degree of vested interests and stability, and thus may create path dependencies in the dynamics of standards. Thus, networks of standard supporters can be a source of network effects as well as of path dependencies and lock-in. We will study phases in the dynamics of standard-supporting networks and standards. Schreyögg and Sydow (2011) and Sydow, Schreyögg and Koch (2009) distinguish three phases in the process of creating path dependencies:

(1) The pre-formation phase: the range of options in the choice of a solution is broad;
(2) The formation phase: self-reinforcing processes narrow the range of options, and the process becomes partly irreversible – a path is evolving;
(3) The lock-in phase: the dominant decision pattern only leaves room for very limited change, since this pattern becomes deeply embedded in organizational practice and is replicated.

According to the authors, specific events trigger the transition from phase 1 to phase 2. Sydow et al. (2009) give the example of the standard for video recorders, where the initial cooperation between the dominant actor, Matsushita, and movie studios for complementary product development (pre-recorded movies) initiated indirect network effects and path dependencies that led to the dominance of VHS.

In this paper we specifically investigate the extent to which different phases can be distinguished in the evolution of standards, how network formation and standard flexibility evolve in the different phases, and how they contribute to path dependencies. We also address the events that trigger the transition between phases from a network perspective. This analysis of the role of networks in path dependency may reveal the conditions under which the co-evolutionary, and sometimes spiral, process between network formation and standard flexibility terminates.

In summary, we explore the antecedents and effects of changes in standards, particularly with respect to the diversity and size of the standard's network. We presume that information exchange within and the collective action of the network of standard supporters leads to a dynamic relation between standard flexibility and network formation. Specifically, we examine the effects that changes in a standard's content have on the size and diversity of the network of standard supporters, and in turn, the subsequent effects of the network's increased size and diversity on further adaptations of the standard. Additionally, we explore the role of the network flexibility dynamics in path dependencies which in turn limit the reciprocal process between the standard and the standard-supporting network.

## Methodology

Since we are the first to conduct a focused study on the relationship between standard flexibility and interorganizational networks, we perform explorative research based on a case study approach, involving an in-depth study of standards battles. We selected three cases of battles between compatibility standards: the battle between Blu-ray and HD-DVD for a high-definition optical disc standard, the battle between Firewire and USB (Universal Serial Bus) for interconnectivity of peripherals to the PC, and the battle between WiFi and HomeRF for wireless connectivity in the home.

For each standards battle, we examined news archives including Factiva and Lexis-Nexis and press releases from the websites of the organizations that develop and promote the standards. We also analysed written documents to gain a general insight on the development paths of the standards. These documents included the minutes of meetings (organized by standards committees and consortia), presentations, press releases and actual standards drafts and specifications. To complement the data and assess the substantiality of each change in the standards, we conducted focused interviews with key persons involved in the development of each standard. Often one interviewee introduced us to a key informant at another company involved in the battle. These contact persons gave us access to relevant documents as well. In total, 15 face-to-face interviews plus 13 telephone interviews were conducted in Europe, Japan and the US. In the case of Blu-ray versus HD-DVD, we interviewed ten respondents, including members of the Board of directors of the Blu-ray Disc Association, the president of the Blu-ray Disc Association, and one of the key members of the HD-DVD promotion group. For the USB versus Firewire battle, we interviewed eight respondents, including Intel's project leader for the implementation of USB and a technology manager closely involved in the development of Firewire. For the WiFi versus HomeRF case, we interviewed ten respondents, including the chairman of the IEEE 802.11 committee (from 1990 to 2000), the co-founder of the WiFi alliance, the former internal WiFi project leader at NCR (the company that initiated the WiFi standard), and a project manager involved in the HomeRF standard. The interviews were conducted between 2007 and 2010 and the length of the interviews varied from 1 to 2.5 hours. To ensure consistency and reliability, we used interview guidelines for all interviews. We communicated the results to the interviewees for verification. We translated quotations from non-English-speaking interviewees into English.

We define the *success* of a standard in terms of market share; a standard is highly successful (dominant) when it has achieved more than 50% market share among new buyers in a certain product or service category for a significant amount of time (Lee, O'Neal, Pruett, & Thomas, 1995; Suarez, 2004). A standard achieves medium success if it survives for a long period of time, but does not become dominant. Low success means that the standard disappears from the market. We define the *network of a standard* as all the connections between two or more actors with the goal of developing and promoting the standard (Mulder, 1992, as cited by Egyedi, 2003). Examples of networks include standardization alliances (Hill, 1997), consortia, and committees of formal standards organizations (De Vries, 1999). We define *network diversity* as the number of relevant industries that are represented in the network. According to Jiang, Tao and Santoro (2010), alliances can be differentiated in terms of degree of variance in partners (industry diversity, national diversity and organizational diversity), functional purposes and governance structure. In our research, industry diversity is the main point of interest. Our definition of standard diversity is based on the notion from network literature that diverse network members use their knowledge and experience to adapt a standard to the requirements of different industry groups, and that the modified standard will attract network members from those new industries. If actors operate in multiple industries, we looked at the divisions within the firm that participated in the network and counted the number of industries in which these divisions were active. *Network size* is defined as the number of companies that supported the standard by, for example, adopting the standard in their products.

*Standard flexibility* is defined as the number and degree of changes since the start of the standard's development. To the extent possible, we distinguish substantial changes from minor changes. Substantial changes are modifications of the specification that are important for the functionality of the standard. Examples are, in the case of Blu-ray, the addition of region coding and copy protection or the removal of a disc cartridge. The first and the second of these changes modified the standard's functionality to the benefit of content providers, and the third lowered cost and improved ease of use. Minor changes are modifications that do not or hardly impact the standard's functionality.

Each interview began by presenting the interviewee with a chronological list of changes for each of the standards, which we deduced from the initial desk research. We asked the interviewee to modify the list where needed. For every change, the interviewee was asked how substantial the change was, which parties proposed the change, which parties were active in drafting the new version of the specification and which parties were involved in approving it. Then, we asked about the reasons for changing the standard. Subsequently, we inquired whether certain changes were incorporated with the goal of attracting other parties to the standard and whether these parties originated from new industries. We also asked whether these new parties contributed to the success of the standard and whether they would have joined had the standard not been changed. Lastly, we asked whether these new parties contributed to the further development of the standard.

The data was analysed following Miles and Huberman's (1994) recommended three steps: data reduction, data display, conclusion drawing and verification. First, we analyse the primary and secondary data marking the events that took place during each standards battle. We focused on changes in the standards and in the networks supporting the standards. This resulted in a historical reconstruction of the standard development, respective changes and support network build-up. To assess how standard flexibility, network diversity, network size and standard success related to each other in each case, we triangulated the evidence obtained from the news archives, written documents and interviews. Based on this triangulated evidence, we derived, for each standard, the values for each variable. We created several displays to evaluate the changes in our constructs of interest over time. We examined the displays and narratives to fully understand each case. We also assessed to what extent different phases can be distinguished in the dynamics of the evolution of each standard. Then, we determined whether patterns could be established for our constructs across different standards battles to arrive at evidence regarding the nature of the relationship between our constructs. This was a highly iterative process in which we frequently reviewed our data to verify and reformulate our claims. It resulted in additional data collection including several follow-up interviews.

## Case study 1: Blu-ray versus HD-DVD

### *Background*

In 1998, the market introduction of commercial high definition televisions in both the US and Japan created the need for a commonly accepted, inexpensive way to record and play high definition content. Two standards competed for dominance; Blu-ray and HD-DVD. In 2008, Blu-ray became dominant (see Table 1 for a chronology).

### *Blu-ray*

At the end of 1997, Sony and Philips decided to combine their high-definition optical disc technologies and develop Blu-ray. Primarily, the consumer electronics divisions of Sony and Philips were involved in the development, but the disc replication and optical disc drive manufacturing divisions of Sony also participated. Sony and Philips developed the new technology to be backward-compatible with DVDs, but substantially better in terms of disc capacity. An interviewee at Philips explained:

> It was a strategic choice to work on a technology with five times more storage capacity than DVD because we believed that in the future motion picture studios would have the need for more disc capacity.

The development started with standards for rewritable discs and disc recorders.

After developing the standard up to version 0.5, Sony and Philips invited other major consumer electronics companies with the goal of preventing a standards battle. Simultaneously, in April

**Table 1.** Chronology of events for Blu-ray and HD-DVD

| Blu-ray | | HD-DVD | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| 2000: Preliminary record-only format finalized | 1997: Sony and Philips (consumer electronics, disc replication and optical disc drive manufacturing) start development | | |
| 2001: Disc storage capacity doubles to 50 GB | 2001: Panasonic (consumer electronics) joins | | |
| 2002: First version record-only format finalized, focus changed to read-only, additional copy-protection and region coding | 2002: Six major consumer electronics companies join | | 2002: Toshiba and NEC (consumer electronics, disc replication and optical disc drive manufacturing) start development |
| 2003: Removal of disc cartridge, change in logical format, new video based application format | 2003: Sony's computer manufacturing and movie studio join | | |
| 2004: First version of read-only physical specifications finalized incorporating bare disc system | 2004: Computer manufacturers (Hewlett Packard, Dell), optical disc manufacturer (TDK), Sony's game console department, movie studios (Walt Disney, 20th Century Fox) join | 2004: First version of read-only and rewritable physical specification finalized. | 2004: Movie studios (Paramount, Universal and Warner Bros.) join |
| 2005: Improved version writable and rewritable physical specification finalized, using bare disc system | 2005: Hewlett-Packard (computer manufacturer) drops exclusive support | | 2005: Software and game consoles (Microsoft), semiconductors (Intel), and computer manufacturer (Hewlett Packard) join. Warner Bros. and Paramount drop exclusive support |

**Table 1.** (Continued)

| Blu-ray | | HD-DVD | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| 2006: Improved version read-only format, new video-based application format, additional copy protection and region coding | | 2006: First version of read-only file system specification finalized | |
| | | 2007: Storage capacity increased to 51 GB | 2007: Paramount provides exclusive support |
| | 2008: Warner Bros (movie studio) exclusively supports Blu-ray | | 2008: Warner Bros. (movie studio), Walmart, Bestbuy and Netflix (retailers) leave. HD-DVD promotion group is dissolved |
| 2009: 3D functionality added | | | |
| 2010: Writable format storage capacity increased to 100 GB | | | |

2001, Panasonic (then known as Matsushita) presented a competing format (Peek, Bergmans, Von Haaren, Toolenaar & Stan, 2009). A respondent from Sony noted:

> Through history, when Panasonic supported a technology, that technology won the standards battle. Therefore Panasonic was an obvious key player that we wanted to attract in the Blu-ray development.

Panasonic was invited to collaborate, which they accepted, and they contributed their dual-layer technology, doubling the storage capacity. The three companies started attracting other large consumer electronics manufacturers and planned to form a group of ten companies. One of them, Toshiba, decided not to accept the invitation and continued to work on its own format, HD-DVD. In February 2002, nine major consumer electronics companies established the Blu-ray Disc Founders consortium. They completed version 1.0 in June 2002.

The new network members made clear that pre-recorded discs and content were required to make the technology successful. This led to a substantial change by parallel development of variations in the standard in different working groups – for rewritable, recordable and read-only discs. In April 2003, Sony introduced the first commercially available high-definition disc recorder for recording HD images, but in Japan only. Consumer adoption was disappointing due to the price and technological problems; production was soon stopped.

With the shift in focus towards pre-recorded discs, the companies supporting Blu-ray realized that gaining commitment from movie studios and the IT industry was imperative. Sony's movie studio and computer manufacturing business joined in 2003. In January 2004, they gained support from the two largest computer manufacturers, HP and Dell. This was done by adhering to their requests to make substantial modifications to the format, replacing Sony's logical format with the non-proprietary Universal Disc Format and working towards a disc without a cartridge. In March 2004, TDK (a leading manufacturer of optical discs) joined the consortium. Their hard-coat technology eliminated the need for the disc cartridge. In order to obtain support from the major Hollywood studios, the Blu-ray Disc Foundation agreed to a new and substantial set of changes in the standard, by including two additional layers of content protection, region coding and a new video application format. According to an executive at Panasonic,

> 20th Century Fox and Walt Disney have fewer, but very strong, titles in comparison to other major film studios, and due to their size it is more difficult to launch movies world-wide on the same date. Therefore, both content protection and region coding are especially important to these two studios.

As a result, between October and December 2004, 20th Century Fox, the Walt Disney Company and Buena Vista Home Entertainment decided to join the Blu-ray consortium. A year later, this also led to non-exclusive support from two other major film studios, Paramount and Warner Bros. (which initially exclusively supported HD-DVD).

In May 2004, before the movie studios announced their support, the 13 members of the Blu-ray Disc Founders created an open platform which any company could join: the Blu-ray Disc Association. This boosted the amount and diversity of company support: three months later, more than 70 companies from the consumer electronics, information technology, media and software industry had joined. The Board of Directors of the Blu-ray Disc Association initially consisted of the 13 founders and over time grew to 19 members. In 2005, the association evaluated its video format, from Sun Microsystems, against Microsoft's video format. It decided to stick with its application for technological reasons and because the movie studios preferred the format. This choice led Microsoft and Intel to choose HD-DVD exclusively. Soon HP followed.

In 2005, at the request of the Japanese government, Toshiba, Panasonic and Sony negotiated to arrive at a common standard. However, the negotiations stalled, leaving it up to the market to decide which technology would win. The first Blu-ray players entered the market in June 2006. In November 2006, Sony launched its PlayStation3 video game console with integrated Blu-ray player. In January 2008, Warner Bros. decided to exclusively support Blu-ray. Warner saw that the market was leaning towards Blu-ray since it had the most support from the consumer electronics and movie studio industry and because of the success of the Playstation3. With four of the six major movie studios exclusively supporting Blu-ray, influential retailers such as Walmart followed. Blu-ray became the dominant standard for high-definition optical discs in 2008. After this victory, the standard was upgraded to keep it up to date, for example, by increasing the disc capacity and integrating 3-D technology. The network's diversity and size remained stable, since the exit of some parties was compensated by new entrants.

## *HD-DVD*

After deciding not to join the development of Blu-ray, in August 2002, Toshiba and NEC announced the competing format, HD-DVD. HD-DVD was built upon the intellectual property of the DVD standard and a combination of new technology from both companies. By building on the DVD format, there was less freedom to modify the HD-DVD standard. Toshiba and NEC had activities in the consumer electronics, computer and optical disc drive industry. They immediately tried to expand the number and diversity of supporting companies by getting it accepted by the DVD Forum, the existing organization for support of the DVD standard. The companies supporting Blu-ray, which were also members of the DVD Forum, managed to prevent this twice. But in November 2003 the DVD Forum decided to officially support HD-DVD. The HD-DVD format became the focus of development in Working Group 11 of the DVD Forum. Adoption by the DVD Forum greatly enhanced the amount and diversity of companies that supported the standard; by March 2004, 79 companies were involved in Working Group 11. The DVD Forum's Steering Committee approved version 1.0 in June 2004. Subsequently, there were numerous follow-up changes. These were often 'optional specifications' that constituted small amendments to version 1.0.

Toshiba and NEC made an effort to gain commitment from movie studios with which they had a good relationship. In November 2004, three of the six major Hollywood studios announced that they would issue movies for HD-DVD. In December 2004, Toshiba, NEC, Sanyo and Memory Tech established the HD-DVD Promotional Group to provide additional momentum behind the standard and to enhance the development of content and hardware made in compliance with the standard. This increased support for the standard: by September 2005, 84 companies were participating in Working Group 11, and 110 companies in the Promotional Group.

In 2005, Microsoft and Intel, dissatisfied with Blu-ray, issued exclusive support for HD-DVD. Microsoft's software and hardware knowledge helped Toshiba with some minor changes to create a fully-formed playback system and special menu features. Microsoft decided to provide an HD-DVD drive as a separate add-on to its Xbox360 game console – a further diversification of HD-DVD's support network. The Xbox360 itself had been launched in November 2005, but only contained a traditional DVD drive.

In March 2006, Toshiba released their first HD-DVD player in Japan and, one month later, in the United States. In 2007, the HD-DVD camp increased its efforts to obtain exclusive support from Hollywood studios, but Warner Bros. decided to exclusively support Blu-ray. As a result, in February 2008, Toshiba announced it was discontinuing manufacture of HD-DVD products and the HD-DVD promotion group was dissolved in March 2008.

## *Case analysis*

This case suggests three phases in the development of each of the two standards. In the first period, a limited number of companies from the same industry started developing the standard. In the second period, the initiators started adapting the standard and inviting companies from other industries. In this phase the standards battle took place. In the third phase, which started when Blu-ray became dominant, the network became stable although the standard continued to be adapted to new requirements.

The size and diversity of the two networks were initially similar, but the dynamics of the processes and the market shares of the network members in their respective industries were different. Some of Blu-ray's new members requested several substantial changes in the content of the standard. These changes also served to attract new members, particularly IT and movie companies, with a significant market share in their respective industries. Specifically the substantial changes that Blu-ray made to accommodate the requirements of the movie studios created higher commitment and support in that sector.

HD-DVD showed less dynamics (see Figure 1). Microsoft's involvement led to minor changes. By incorporating the DVD Forum in the network, Toshiba and NEC created a large and diverse

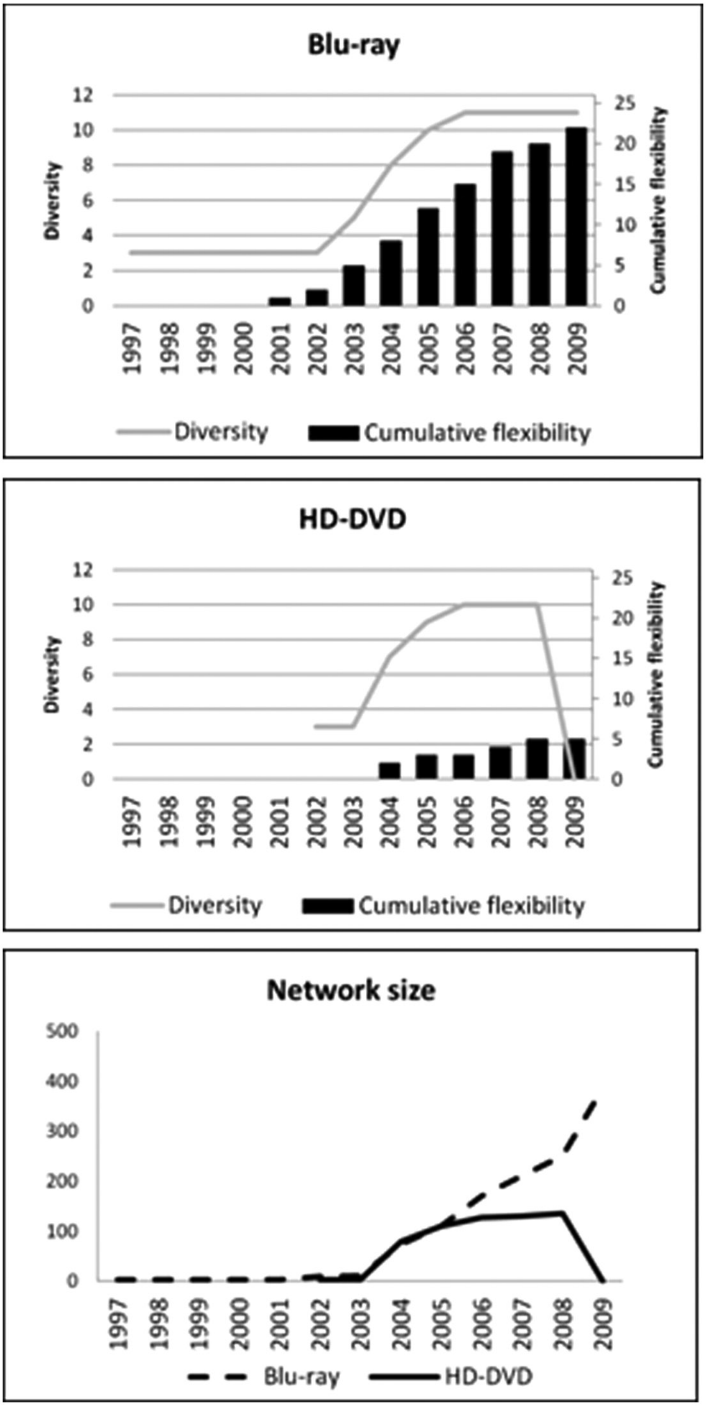


**Figure 1.** Network size, diversity, and standard flexibility for Blu-ray and HD-DVD (standard flexibility relates to the number of major changes only)

network, but this network was less committed since the standard had not been adapted to the requirements of the network members from the beginning. The reason for Toshiba and NEC's strategy of requesting adoption by the DVD Forum was that they were later in the process of inviting other companies, and support by the DVD Forum was the fastest way to build up industry support.

Other reasons for the difference in dynamics are, first, that HD-DVD had more technical limitations to modification than Blu-ray due to the initial choice to use DVD technology, and second, because the development of HD-DVD started later than Blu-ray. Therefore Toshiba focused on completing the format and did not want to delay market introduction by modifying the format. HD-DVD eventually had the advantage of being slightly earlier to the market, and at a lower price, whereas Blu-ray's technical superiority was not a strong driver for consumer adoption. Thus, this case also shows that price, early timing of market entrance and technical superiority are of influence, but are not decisive. By being more flexible and adhering to some of the wishes of non-participating stakeholders, the Blu-ray supporters managed to bring these stakeholders on board with a high level of commitment; once on board they more often than with HD-DVD provided exclusive support to the format.

## Case Study 2: Firewire versus USB

### *Background*

Peripheral computer devices such as speakers and webcams and products like digital cameras, requiring connection to the PC, arrived on the market in the 1990s. Two standards emerged specifying this connection: Firewire and USB. USB achieved dominance but Firewire continued to be used in specific niche markets (see Table 2 for a chronology).

### *Firewire*

Apple started to develop its Firewire standard in 1986. The first version was ready in 1987. Apple submitted it to the Institute of Electrical and Electronics Engineers (IEEE) in order to obtain support for the standard. It was difficult for other companies to influence the further development of the standard because Apple sent many experts to the committee. One respondent noted: 'Apple was sitting on their core standard as a chicken protecting her egg; nobody was allowed to touch it.' In 1995, the standard was ratified as IEEE 1394. The consumer electronics industry perceived the need for greater bandwidth capacity and from 1995 companies such as Sony became involved. One respondent noted:

> People do not accept it when the television suddenly malfunctions whereas PC people accept it because they can press the reset button … Therefore, at the time, we chose the Firewire standard because we knew that this standard would always function properly.

As a result, network diversity increased from one (Apple, computer manufacturer) to two (consumer electronics). Actors from other relevant industries such as semiconductors, pre-packaged software and computer networking were not involved. In 1994, Apple established the 1394 Trade Association, open to all companies that wanted to implement the standard in their products.

In 2000, IEEE 1394a was ratified, enabling higher efficiency and additional functionality (such as streaming). In 2002, IEEE 1394b was ratified, enabling a higher bandwidth capacity and reliable

**Table 2.** Chronology of events for Firewire and USB

| Firewire | | USB | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| 1987: First version finalized | 1986: Apple (computer manufacturer) starts development of Firewire | | 1992: Intel (semiconductors) starts development of USB |
| 1995: Data rate increases to 400 mbps | 1995: Consumer electronics industry (e.g. Sony) joins | 1994: First version USB finalized<br>1996: Data rate increases to 1.5 mbps<br>1998: Data rate increases to 12 mbps | 1995: Computer manufacturer, pre-packaged software, and computer networking industry join |
| 2000: Changes incorporated enabling higher efficiency and additional functionality such as streaming<br>2002: Date rate increases to 3200 mbps. Changes incorporated to enable more reliable data communication over longer distance<br>2006: Changes incorporated enabling interconnection with Ethernet-based local area networks | | 2000: Data rate increases to 480 mbps<br>2006: Functionality added to enable USB peripherals to communicate directly with each other<br>2007: Battery charging functionality added<br>2008: Data rate increases to 5000 mbps | 1999: Consumer electronics (Philips) and telecommunications (Lucent) industry join |

data communication over a longer distance. The intention was to make the standard appropriate for new areas such as home networking and automotive electronics. Some companies from those industries adopted the standard, which increased the size of the standard-supporting network. Also, more computer manufacturers adopted the standard; their interest was driven by the standard's increased speed which could be used for the internal bus within the PC.

From 2002 to 2008, additional changes were incorporated in the standard which further strengthened the standard's position in its high-bandwidth niche market. For example, in 2006, an interface specification was added which enabled interconnection with Ethernet-based local area networks. The size and diversity of the support network remained stable.

## USB

Intel started the development of the USB (Universal Serial Bus) in 1992. When, in November 1994, the standard was developed up to version 0.7, they decided to formally sign-up other companies. According to Intel's USB project leader: 'A personal computer is based on open interfaces, but the industry does not trust an "open standard" developed by just one company.' Intel wanted the group's size small enough for rapid progress, but large and diverse enough to sufficiently represent the industry. Intel scheduled a meeting in which it invited several companies, including Apple, to present the specification they prepared. However, Intel did not want to further collaborate with Apple because of Firewire.

In March 1995, Intel established a two-tier alliance; the USB Promoter Group (for developing and promoting the USB standard) and the USB Implementers Forum (open to a larger group of firms in order to create products and market momentum). The standard-supporting network became diverse: semiconductors (Intel), computer manufacturers (Compaq, IBM), pre-packaged software (Microsoft), computer networking (Northern Telecom) and companies operating in several of these industries (DEC, NEC).

Between versions 0.7 and 1.0 there were no substantial changes to the standard; only details were refined. Version 1.0, launched in 1996, enabled a data rate sufficient for data communication between personal computers and peripheral devices. This capacity improvement satisfied the direct needs of the companies involved in the USB Promoter Group. In order to build industry momentum, the USB Promoter Group organized compliance workshops for peripheral suppliers and a conference for developers. This resulted in the rapid increase of members in the USB Implementers Forum. New companies, including suppliers of personal computers and consumer electronics, were invited to participate and suggest changes in the standard. This led to several extensions to the standard. One respondent noted: 'If we can think of a couple of applications for the standard and establish working groups for these applications, then automatically the standard will be implemented in more products.'

USB version 1.1 was introduced in 1998 to increase USB applications and make the standard fit for audio, voice and video by increasing data rate. As a result, Philips (consumer electronics) and Lucent (telecommunications) joined the USB Promoter Group in 1999. Their membership increased network diversity and the legitimacy of the standard in the eyes of potential adopters. New participants became involved in the further development of the standard. The USB representative at Philips noted: 'In USB 1.1, it was certainly not possible to get a good quality audio signal over USB. In that respect Philips certainly contributed to the standard. We also contributed to making the USB hub more robust.' As a result, more consumer electronics companies chose to adopt the standard.

In 2000, USB version 2.0 was introduced, enabling an even higher data rate. As a result, many companies from different industries including consumer electronics, digital photography and data storage chose to adopt USB for products such as video peripherals and hard disks. After 2000, additional functionality was added to the standard through many changes (e.g. battery charging functionality through USB, and the possibility for USB peripherals to communicate directly with each other). As a result the standard attracted many producers of complementary products (including MP3 players, external hard drives and mobile phones). The number of companies supporting the standard grew from 600 in 2000 to 900 in 2002. After 2002, the number of supporting companies remained constant. Since 1999, the diversity in the Promoter Group has also remained more or less constant; some parties left the group while others joined.

### *Case analysis*

Similarly, in the case of Firewire and USB, the three phases can be distinguished. Single companies, Apple and Intel, started the development of the two standards, Firewire (1986) and USB (1992), respectively. In the second phase, after one or two years, each standard initiator decided to seek broader support. Apple did this by participating in IEEE. Consumer electronics companies in need of high capacity joined and the group upgraded the standard (higher data rate). The 1394 Trade Association was established to bind implementing companies together, and membership grew steadily. However, the dominant role of Apple and its reluctance to allow major changes in the standard hampered other companies in coming up with suggestions to improve the standard. As a consequence, the group did not take full advantage of the opportunities of attracting other actors to the network. Figure 2 shows that the number of changes remained relatively low, while network diversity and size were lower for Firewire than for USB. Nevertheless, the standard acquired sufficient support to maintain a foothold in the high-bandwidth niche market.

Intel aimed for a cheap standard with a broad application. It was more active in its attempts to extend the network. Figure 2 shows that they allowed many more modifications and were more successful in terms of size and diversity of the network. The standard supporters also created a separate 'Implementers Forum' and actively invited parties to propose modifications of the standard. This strategy resulted in the network's growth in both size and diversity as well as growth in the standard's market use. The case thus confirms our expectation that changes in the standard can facilitate the growth of network size and diversity, and thereby increase the standard's chances of success. But the case also shows that the attitude and behaviour of the dominant actor or actors with respect to flexibility can have substantial influence.

The process came to a halt around 2002 when the growth in size and diversity of the networks of both standards ended, entering the relatively stable third phase. To date, USB outperforms Firewire considerably in market share, but Firewire keeps its niche. Users can choose between the two standards although in most cases they opt for USB. Only in some cases of high-bandwidth capacity is Firewire preferred. After 2002, both standards continued to change and we cannot exclude the possibility that future upgrades of USB may affect Firewire's position and vice versa.

## Case Study 3: WiFi versus HomeRF

### *Background*

The third case describes the battle between two standards for commercial wireless data communication: WiFi and HomeRF. The battle resulted in a clear winner: WiFi has become the dominant standard for wireless networks in homes and offices (see Table 3 for a chronology).

### *WiFi*

In 1985, the Federal Communications Committee (FCC) passed a ruling which made commercial wireless data communication possible in the US. This triggered National Cash Register (NCR) to

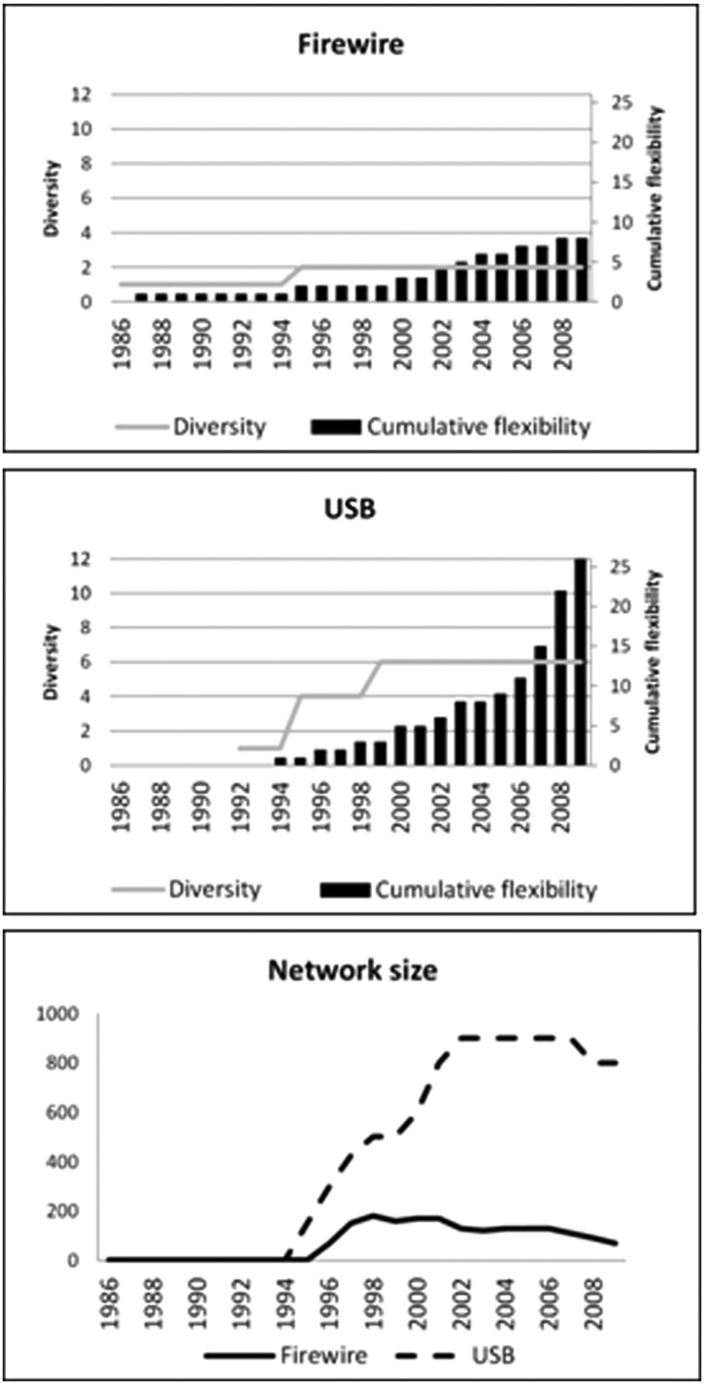


**Figure 2.** Network size, diversity, and standard flexibility for Firewire and USB (standard flexibility relates to the number of major changes only)

**Table 3.** Chronology of events for WiFi and HomeRF

| WiFi | | HomeRF | |
|---|---|---|---|
| Events relating to standard | Events relating to network | Events relating to standard | Events relating to network |
| 1997: First version WiFi finalized<br>1999: Data rate increases to 11 mbps (over the low band) | 1985: NCR (Computer networking) starts development of the standard<br>1990: Computer manufacturer industry (e.g. IBM) joins<br>1998: Telecommunications industry (Breezecom) joins | 1998: First version HomeRF finalized | 1997: Intel (semiconductors) starts development of the HomeRF standard together with firms representing pre-packaged software, computer manufacturing, telecommunications, and consumer electronics industries<br>1999: Consumer electronics industry leaves |
| 2000: Data rate increases to 54 mbps (over the high band)<br>2003: Data rate increases to 54 mbps (over the low band)<br>2004: Changes incorporated to resolve security issues and to support more frequencies<br>2005: Functionality (streaming) added<br>2008: Changes incorporated: higher efficiency (reduced power consumption) and additional functionality (fast roaming)<br>2009: Data rate increases to 600 mbps | 2000: Consumer electronics industry (Philips) joins<br>2002: Pre-packaged software industry joins<br>2003: Boeing joins | 2001: Data rate increases to 10 mbps | 2000: Pre-packaged software industry leaves<br>2003: Network disbanded |

begin a study into the feasibility of a wireless radio for cash registers sold in the US. The goal was to achieve the highest possible bandwidth capacity so that wireless communication would feel like wired communication. The data from the banking terminals and cash registers had to be downloaded in the morning. The project leader explained:

> When you come in with a wireless solution and you say that you could move the cash registers around anywhere you want that's fine, but you can't say 'And by the way when you turn it on in the morning you will have to wait for half an hour'.

A small team of engineers worked on successive prototypes.

In 1988, NCR engaged with the IEEE to identify an appropriate wireless protocol for the standard. In 1990, the IEEE 802.11 working group was established. From 1990 to 1997 it was mostly computer manufacturers (such as IBM) and computer networking manufacturers (such as NCR) that were active on the committee. The standard was finally approved as IEEE 802.11 in September 1997. In 1998, Breezecom joined, later followed by other telecommunications companies such as Nokia and Motorola. This increased network diversity. Earlier, work had started on two specifications for a higher bandwidth capacity. Wireless data communication was possible in two frequency bands, low and high. In some countries, the low band was reserved for other purposes and the only option was to use the high band. In France, for example, the organizers of the Tour de France had exclusive access to the low band. At the November 1996 meeting, two projects were established: project 802.11b for a low-bandwidth capacity over longer distances in a low band and project 802.11a for a high data rate over shorter distances in a high band. These revisions, enabling speeds of 11 megabit per second (mbps) and 54 mbps, were approved in December 1999 and January 2000, respectively. The IEEE 802.11 committee chairman explained the importance of increased bandwidth capacity:

> At that time Ethernet [a wired alternative for WiFi] already guaranteed a data rate of 10 mbps so consumers perceived the data rate of 2 mbps to be too slow. To respond to their wishes we began work on an extension for a higher data rate.

The former CTO of NCR added to that: 'We were always trying to keep up with the wired equivalent of the LAN … You always had this sort of data rate hungry appetite.' The increased bandwidth capacity attracted many companies to the standard. In 2000, the diversity in the network increased further as consumer electronics companies (such as Philips and later Samsung) joined. In 1999, the Wireless Ethernet Compatibility Alliance (WECA) was established in order to promote the standard and certify products. This further increased network size.

From 2000 onwards, many companies became active in the IEEE 802.11 committee and established different task groups which each worked on several enhancements to the IEEE standard. The committee also specifically invited firms to form task groups to ensure that certain required changes would be incorporated in the standard. As the chair of IEEE 802.11 commented:

> We began with a standard that worked, then you can adapt that standard and by doing so create a larger market for it … Through these changes the number of applications that can make use of the standard increases and so more companies joined.

Many revisions were developed which resulted in an increase in complementary products that could make use of the standard and, subsequently, in an increase in the number of companies that adopted the standard. Also, network diversity continued to increase. In 2002, the pre-packaged software industry (Microsoft) joined and in 2003, the aircraft industry (Boeing). Boeing wanted to use WiFi in its manufacturing process. However, for them the connection had to be more reliable as planes are built in an environment with a lot of reflections creating background noise. After 2003, the diversity in the network remained constant over time while the size of the network gradually increased.

## HomeRF

In 1997, Intel established the Home Radio Frequency Working Group to develop a standard for wireless communication of both data and traditional telephone signals. At that time, WiFi was not fit for providing home telephone applications of sufficient quality. Working group participants covered semiconductors (Intel), pre-packaged software (Microsoft), computer manufacturing (e.g. Compaq), telecommunications (e.g. Ericsson) and consumer electronics (Philips). From 1997 to 1998, several meetings were held, resulting in a first standard (version 1.0). As one respondent noted:

> The initial meetings were very open, everybody was encouraged to work on the first HomeRF specification with the rules of the FCC that, at that moment, applied … The development process was very efficient and quick; there was little friction between the members as they were highly committed.

The FCC rules implied that the bandwidth for ‘frequency hopping’ could reach a limited capacity. The HomeRF workgroup chose the ‘frequency hopping’ modulation technology instead of the ‘direct sequence’ modulation technology since devices that implement ‘frequency hopping’ are cheaper, use less power and are more reliable. In that respect they were not as flexible as WiFi, which chose to support both modulation technologies in its standard.

Later, HomeRF meetings were less efficient. As one respondent noted: ‘In later meetings some of the big firms in the developing process had some serious doubts about the standard … They disagreed about the standard.’ As a consequence, it took a long time before the members could agree on additional changes to the standard. In 1999, Philips left the group, followed in 2000 by Microsoft. The main reason for departure was that the choice to stick to the ‘frequency hopping’ modulation technology could not provide them with the higher bandwidth capacity they required.

In 2000, the FCC changed the rules for frequency hopping, enabling higher bandwidth capacity. Following that decision, the Working Group started to develop a new generation of the standard. However, as one of the members noted: ‘The FCC ruling came just too late for us.’ Indeed, by the time HomeRF 2.0 was introduced (2001), WiFi had also been upgraded sufficiently. Intel left the group, causing many companies to follow. Eventually, the Working Group was disbanded.

## Case analysis

The development of the WiFi standard started in the second half of the 1980s, when NCR saw a business opportunity in developing a solution for wireless interconnection. Around 1988 they recognized that they needed others, primarily for knowledge (protocols), and engaged with IEEE, which formed a working group. The diversity of the group was relatively low, but nevertheless it had difficulty making decisions. As Figure 3 shows, the group needed six years to develop the standard. Due to the lack of diversity, this standard did not meet all market needs.

In 1997, Intel initiated the development of a competing standard for high-quality wireless phones at home. They immediately involved other companies and together established a consortium. They invited more companies so they were fast in establishing a broad and diverse network. This triggered the IEEE committee working on WiFi to create additional organizational

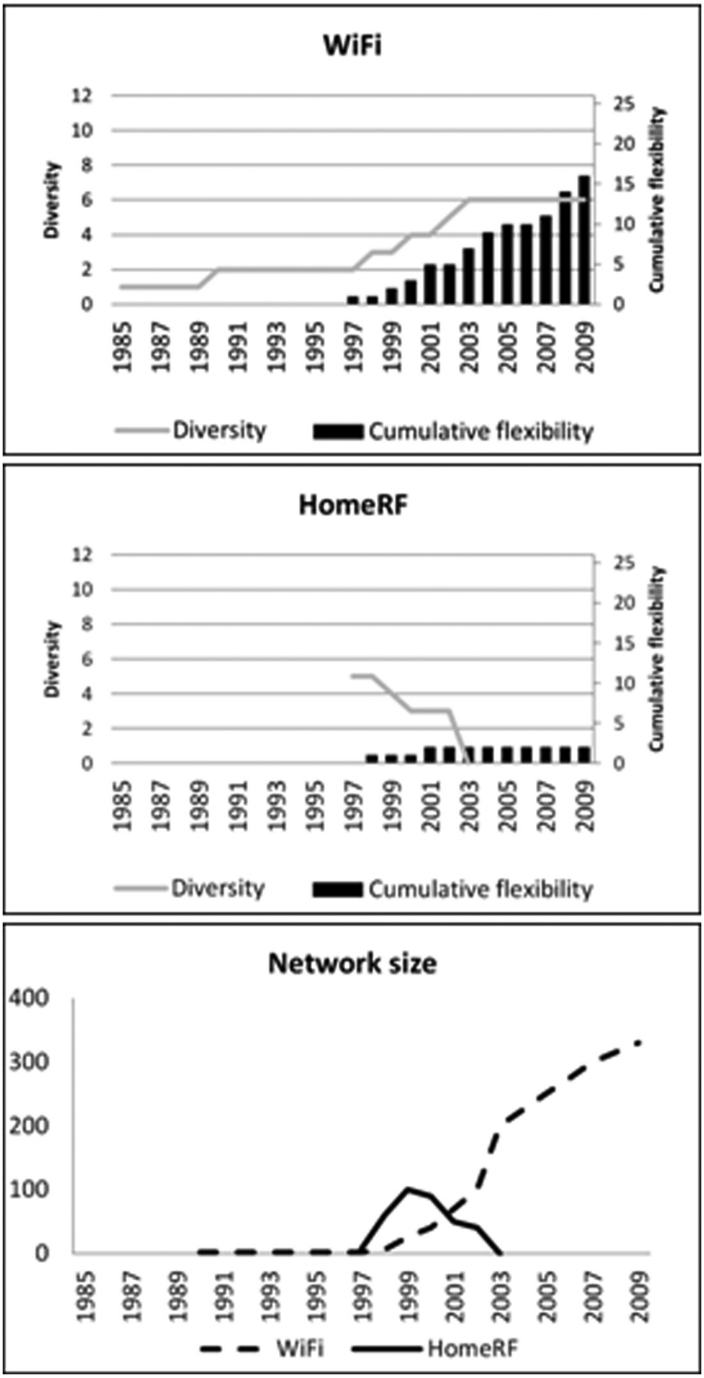


**Figure 3.** Standard flexibility, network diversity, and network size for WiFi and HomeRF (standard flexibility relates to the number of major changes only)

opportunities for participation: anyone could propose changes and form ‘task groups’ to address the proposed changes. As a result, participation increased in both numbers and diversity. However, while HomeRF had a head start with highly motivated participants, the group gradually faced more problems in achieving consensus; they became too slow in upgrading the standard. They stuck to their initial technological choices, resulting in a standard that enabled a comparatively lower bandwidth capacity in only one frequency band. WiFi, on the other hand, was more flexible; it chose to support two modulation technologies in its standard instead of one and developed a standard for both of the available bands. Furthermore, they sought improvements not only – like HomeRF –in bandwidth capacity, but also in other functionality. As a result, many companies left HomeRF and chose to support WiFi. The size and diversity of the HomeRF network decreased considerably. The companies that left HomeRF chose to adopt the WiFi standard, contributing to its dominance. It made no sense for HomeRF to continue, so the consortium was dismantled. This marks the start of the third phase, in which, as Figure 3 shows, work on improving WiFi continued and its network grew further in size, but not in diversity.

So, both standards initially obtained a similar network diversity. The explanation for the higher success of WiFi and the failure of HomeRF is mainly related to the flexibility of the standard. Due to lower flexibility, industries left HomeRF, and the use of the standard diminished.

## Cross-Case Analysis

The cases show that the evolution of each standard was characterized by three phases. In the initial phase, one or a small group of firms, often from a single industry, took the initiative to develop the standard. In the second phase, they invited additional companies, often from a diverse set of industries, to support the standard. In this phase, the more successful standards (Blu-ray, USB and WiFi) show a strong increase in the size and diversity of the standard-supporting network. More than their competitors, the networks of standard supporters each made substantial changes to the standard. As a result, new actors joined. In the case of Blu-ray, firms in the consumer electronics, disc replication and optical disc drive manufacturing industry started the development, but adaptations of the standard helped to include companies from the computer manufacturing industry and movie studios. In the USB case, a company from the semiconductor industry started the development, later joined by other companies from other industries and the standard was modified to include consumer electronics and telecommunications firms. In the WiFi case, companies from the computer networking industry started the development, but they managed to involve consumer electronics and other companies by adapting the standard. The additional companies were invited at a point when they could have sufficient influence on the specifications; the standard still had substantial development flexibility. These companies subsequently collaborated to develop improved versions of the standard. In the third phase, both the support network of the standard and the market position of the standard were relatively stable (dominant, surviving or disappearing).

In the cases of the less successful or failed standards, the dynamics between flexibility of the standard and size and flexibility of the network took place to a lesser extent. Firewire lacked flexibility, network size and diversity, explaining its minimal success. The strategy of Apple as the dominant actor was the main reason. In both of the other cases, the degree of diversity of the networks supporting the failed standards (HD-DVD and HomeRF) was relatively high but the flexibility of the standard remained low. In the case of HD-DVD, the main reason was the initial choice to make use of existing DVD technology (for reasons of Intellectual Property Rights; IPR), which limited flexibility considerably. The higher flexibility of the Blu-ray standard led to higher commitment. In the HomeRF case, the actors valued aspects such as reliability of the data connection more than increasing the data rate, whereas the latter turned out to be decisive for market acceptance. As a result, important actors left the HomeRF Working Group and joined WiFi instead. So, in this case the initial diversity did not lead to flexibility and thereby diversity did not continue to grow over time.

## Discussion and Conclusion

This paper focuses on the relationship between standard flexibility and network evolution. We investigated the reciprocal relation between changes in standards and changes in interorganizational network size and diversity. We made an exploratory study of three cases of standards battles. In each, we investigated the networks of the two most prominent standards in the battle.

Our cases provide clear support for the existence of a reciprocal relationship between standard flexibility and network formation. Successful standards showed more dynamic interactions between standard flexibility and network formation, in particular during the second phase of the process. The paradox of standard flexibility appeared to entail that flexibility involves a temporary instability of the standard, but contributes to the standard's acceptance which results in stability. Changes in the standard's contents led to the inclusion of new actors in the network, often from new industries, thus increasing both the size and diversity of the network. In some cases, these changes were made with the deliberate intention of attracting new companies, and then often the changes in the standard and in the network took place simultaneously. In other cases, the extension of the network occurred later (e.g. Boeing in the WiFi case). Network extensions sometimes led to further adaptation of the standard's contents in order to meet requirements of existing and potential new network members. This process created a spiral co-evolutionary process of standard flexibility and growing network diversity, leading to increased network size. In the case of Blu-ray, standard flexibility also appeared to increase actors' commitment, strengthening the ties in the network as compared to the competing HD-DVD case. For the less successful or failed standards the co-evolutionary process took place to a lesser extent, for different reasons. In the Firewire case, the central actor, Apple, allowed only minimal changes to the standard, and as a consequence the network did not grow sufficiently to make the standard a real success. In the HD-DVD case, initial choice of technology was the main reason. In general, our cases show that creating the reciprocal evolution between standard flexibility and network formation is key to the success of the standard. We visualized the most important relations in this process in Figure 4. We did not include the

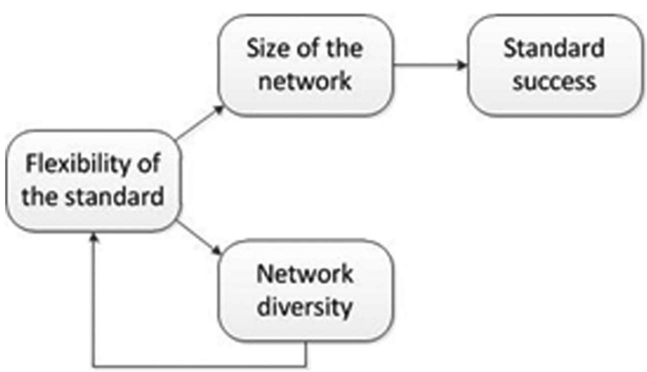


**Figure 4.** Relations between flexibility, network characteristics and success

effects of flexibility on commitment of actors, since the Blu-ray case is the only one in which we clearly observed this effect.

Our cases suggest that early timing of the co-evolutionary process between standard change and network build-up was important for the outcome of the battle, and even more important than an early start of the standardization process itself (Takahashi & Tojo, 1993). In two cases, Blu-ray and USB, the standard network that was earlier in engendering the relationship between standard flexibility and the network achieved dominance. Firewire started much earlier than USB, but still USB was more successful. In the third case, WiFi started earlier but initially made hardly any progress. The start of HomeRF triggered the WiFi consortium to become more active and, better than HomeRF, create the dynamics between flexibility and network formation.

We also observed an increasing degree of path dependency in the evolution of the standards. In the first phase, the initiators had a broad range of options for the standard. In the second phase, the room for choices in the standard's specifications was still clearly available, but diminished for three reasons. First, existing network members and market applications of the standard, and the growing diversity of the members, limited the range of options. This is the reason of lock-in (Arthur, 1996). For instance, we saw that the Blu-ray Disc Association did not adopt technology from Microsoft because the new technology conflicted with the interests of some of the already committed companies. Second, inherent inflexibility of standards themselves could restrict changes in this phase (Egyedi & Blind, 2008; Thomke, 1997). Inherent inflexibility refers to the lack of capacity to change functioning (De Haan, Kwakkel, Walker, Spirco, & Thissen, 2011) resulting from the technical specifications laid down in the standard, which limit the room for later adaptations. Inherent inflexibility is established at the start of the process and potentially causes a trade-off: in the beginning it may create an advantage in the price of the products or a shorter time-to-market due to simpler product development. This may increase the standard's initial success. However, in the second phase of the process, inherent inflexibility limits the standard consortia in developing and changing the standard specifications to address the needs of new product and market combinations. For example, in the case of HD-DVD, a large and diverse group of firms were included in the network of the standard, but the choice to base the HD-DVD on DVD technology limited standard flexibility. The standard could not provide the level of interactivity and security preferred by movie studios, and consequently the network co-evolution process hardly took place. Third, our cases showed an example of restriction of the number of alliance members to keep decision-making manageable (Das & Teng, 2002). In the USB case, Intel preferred the group to remain small. This also limited the co-evolutionary process between standard flexibility and network formation. However, the USB consortium solved the problem by creating a parallel group to implement the standard (the USB Implementers Forum). In phase 3, the room for changes in the standard was lowest. Particularly market implementations limited the room for change in this period. Nevertheless upgrades continued, sometimes in the form of variations next to the main standard.

We see that the networks of organizations supporting the standard were one of the reasons for the emergence of path dependency, particularly in the second phase of the process. Over time, the increasing installed base of network partners that have implemented the standard limited the freedom to adapt the standard, and thus flexibility. Standards, by definition, are intended and expected to 'freeze' a solution and thus to stabilize after a certain period (De Vries, 1999; Verman, 1973). In this paper we show that the flexibility in the process before the freeze is most influential on success.

## Theoretical implications

Our results have implications for the standardization and general network literature. The standardization literature recognizes that the size and diversity of the network are important for standard success. For instance, Cusumano et al. (1992) showed that size of the network contributes to standard success because network members use the standard, leading to a higher installed base. Others have shown that the size of the network also signals market support, causing others to follow (Katz & Shapiro, 1985). Rosenkopf and Padula (2008) studied the evolution of standardization networks but did not include the effects on the success of standards. Our study confirms the effects of networks on outcome, but shows that the content of the standard itself contributes to network formation. Some authors have already investigated the relation between diversity and content of standards. They argued that a diverse network contributes to reflecting the needs of more different user groups in a standard's content, and that a more user-oriented standard will attract more supporters and products, and generate better sales (Cargill, 1997; Evans et al., 1993; Lundval, 1995; Markus et al., 2006). However, these authors apply a static perspective in the sense that they suggest that diversity would be required at the start of the standard development process to exert its one-time positive effect on the standard contents. We add by showing that the relation between diversity and standard contents is dynamic and develops in a co-evolutionary manner over time. We even show that networks of organizations supporting a standard do often start from a single industry and that diversity increases only in the second phase while the standard is modified. In doing so, we follow Rosenkopf and Padula's (2008) recommendation to connect network evolution to technological trajectories.

Remarkably, data from earlier case descriptions in the standardization literature (Funk, 2002; Schmidt & Werle, 1998) implicitly illustrate the dynamics addressed in this paper. However, the authors do not reflect on the influence of the change on the acceptance of the standards. For instance, Cusumano et al. (1992) mention that Sony adapted the Betamax standard (to facilitate two hours playing time) before seeking new partners. In this case the change in the standard prolonged the life of the product, but did not rescue it in the longer term, which partly justifies the lack of attention for it by the authors. In a study of conflict resolution in standardization processes, Schmidt and Werle (1998) mention that in the battle for the fax standard, one of the consortia, led by Matsushita and NEC, increased support for its solution by including a specific modulation system. The authors do not mention this change in the standard when they discuss the reasons for the dominance of the standard. Leiponen (2008) shows that firms propose changes to standards in an attempt to influence the contents of the standard to their own advantage but not as a strategy to create dominance of that standard in competition with other standards. The same emphasis on competition between committee participants is given by Funk (2002) who describes that in the development of the GSM standards for mobile telecommunications German and French technology was deliberately added to the initial standard specification to enlarge the network with firms and governments in those countries. Both were essential for common European support for the standard. These examples suggest that the dynamics addressed in this paper are more widespread in standardization processes, but are often interpreted only as competition within committees and not as part of the dominance battle between that standard and competing ones.

Another contribution of this paper to the standardization field relates to the topic of Funk's (2002) study, the distinction commonly made between coordination via 'committees' and 'markets'. Committees involve explicit communication and negotiation before irrevocable choices are made. The market mechanism involves no explicit communication and depends on unilateral irrevocable choices: it succeeds if one agent chooses first and the other(s) follow(s) (Farrell & Saloner, 1985, p. 235). Our cases show that this distinction does not hold – agreement in a committee does not guarantee market acceptance, since committee standards may also have to compete for acceptance in the market. Leiponen (2008) has already shown that committees and consortia complement each other in standards development, but she only shows how consortia served as preparation for committee decisions. In her cases, those decisions were final. Our study shows that committees and consortia may also compete in the market, that committees and consortia sometimes support the same standard in the battle, and that committees are not necessarily the winners. Both committees and consortia are networks as such and may be part of a larger network including non-members of the committee or consortium. The strength of this overall network is an important factor for success.

Our findings are relevant for the literature on path dependency (Arthur, 1996; Shapiro & Varian, 1999). While that literature has concentrated on the economic mechanisms behind path dependency of standards, we focus on the role of the networks of organizations supporting a standard. Inter alia, we demonstrate that existing network members pose their requirements with respect to standards, in that way creating path dependency during the development process. We also showed how we can recognize three different phases in this process, similar to the three phases that Sydow et al. (2009) distinguish. The similarity of our phases with those of Sydow et al. appears mainly from the scope of action in each phase: broad in the first phase, a narrowing range of options in the second phase, and lock-in in the third phase. We contribute to their theory in several ways. First, we show that concrete mechanisms, particularly interorganizational networks and their characteristics and inherent inflexibility, are antecedents of the diminishing scope of action in the different phases, so of the path dependency process. Second, we show that networks are not a simple cause of the scope of action, but that choices made within this scope (changes in the standards) strengthen the network. And thirdly, while Sydow et al. (2009) demarcate the first phase from the second by means of a rather unspecified 'critical juncture', we defined the transition between the phases based on changes in the diversity of the standard-supporting network. In the first phase a limited group of actors use their freedom to define a first version of the standard; the second phase shows the dynamics between involving more diverse stakeholders and adapting the standard; and in the third phase there is less or no adaptation of the standard and the stakeholder network is stable.

Our study also contributes to the investigation of the network-outcome dynamics in the general network literature. Two types of network outcomes can be distinguished: the definition of the object to which the network refers (the standard, a research project, an NPD project, a commercialization project) and the degree of success of the network. Our project investigates the influence of changes of the first type of outcome, in our case the contents of the standard, on network characteristics, and thereby on the second type of outcome, the success of the network. The literature on networks of organizations is paying attention to the formation process of networks. For instance, Doz, Olk and Smith Ring (2000) explored the relations between environmental factors, partner behaviours and performance in the formation process of networks, but did not address the network-outcome dynamics. This network-outcome dynamics may also be evident in other areas of network collaboration, such as NPD alliances, where adapting the product design may help to interest new partners in the alliance and increase commitment. Another contribution of our study to this field concerns the effects of diversity of networks. Both positive effects of network diversity on performance (Brass et al., 2004) and U-shaped relationships have been found in the literature (Jiang et al., 2010). Our study supports the first view by suggesting a positive effect of industry diversity on performance in the context of networks of organizations supporting a standard.

Finally, this paper contributes to the literature on co-evolution. Several authors have emphasized co-evolution between firm behaviour and firm environment (Lewin, Long, & Carroll, 1999;

Koza & Lewin, 1999). Authors in this field hold that firms have reciprocal relationships with their environment, leading to specific outcomes. Our paper contributes to this literature by addressing, not just co-evolution between developments between single firms and their environment, but the interaction between the development of networks of organizations and one of the main outcomes of those networks, the changing contents of standards. As indicated above, we also address the endogenous and exogenous forces that bring the co-evolutionary process to a stable state.

### Implications for practice

The outcome of standards battles depends on the amount of industry support for the standards, including a willingness from manufacturers to use the standard for their products and customer decisions to buy these products. These groups differ in the needs they may have. Our study shows that it is important to involve a variety of manufacturers and in some cases professional customers too (see our example of Boeing) in the development of the standard; and, if necessary, to adapt the standard to meet their requirements. This can be done before they belong to the network, in order to persuade them to join, but also once they have joined opportunities to propose modifications (such as upgrades) to the standard should be provided. Our study shows that the adaptations of standards over time should not be considered an unwanted side-effect, but an integral part of the standardization process – a part that should be carefully managed.

Our study indicates the importance of timing. Being early to incorporate changes appears to be important for success, and potentially more important than just early timing of market entry (Schilling, 2002). The phases we distinguished may be helpful in this respect. They suggest that it may be more appropriate to make a jump-start with just a few actors who possess essential know-how than with a bigger and diverse group. However, the latter is essential to prepare for broad market acceptance and to prevent essential stakeholders from joining a competing alliance. Thus, the process of expanding the initial network and adapting the standard (phase 2) should be started early. The network can then be gradually extended further – the required speed also depends on what the competing standards alliances, if any, do. Creating a layered network structure in which modifying activities on the standard are separated from standard promotion keeps the processes manageable. Flexibility of the standard may be hindered by inherent technical limitations and therefore it makes sense to be aware of possible later changes in the standard when making initial technical choices. It may be a disadvantage in the beginning (higher costs), but an advantage in later phases. During the third phase, adaptations may be needed to keep pace with technical progress and keep the standard attractive to the members of the alliance, but the implications of modifications for the network become less prominent in that phase.

### Limitations and future research

Of course this study has its limitations. One limitation concerns our measures. In our description of our cases, we distinguished minor versus substantial changes in standards. Although we asked our respondents about the significance of every change, we had no hard criterion to make the distinction. Future research should develop more objective measures regarding the size of standard changes. For instance, this set of measures could be based on an analysis of the technical contents to come to an even better understanding of the influence of standard flexibility.

A second limitation of this study was its exploratory nature. As such, we performed in-depth casestudies. Future research should validate our findings with large-scale empirical research. More longitudinal studies are needed which include other factors, such as additional, structural network characteristics, power relations in networks (Knoke, 1990), technological developments and changing customer requirements over time.

As a third limitation, we focused on two characteristics of standard networks – diversity and size. We briefly touched upon a third characteristic, tie strength, when discussing the role of commitment in the Blu-ray vs. HD-DVD case. Future studies should also address the relation between other network characteristics and network outcomes. An interesting avenue for future research in this line is to further investigate the roles of committee networks versus consortia networks. As we indicated above, these are not separate worlds, but these two standardization processes co-exist and interact, and some parties may be a member of the two types of networks, creating ties between them. An interesting question concerns the effects of these two types of networks and their interaction on standard success. In addition, the role of the layered network structures mentioned above can be integrated in such studies.

Fourth, our study was confined to compatibility standards, which define interrelations between entities in order to enable them to function together. Typically, such standards describe a solution whereas other types of standards may provide performance criteria or a method for measuring. However, we expect that our findings also apply to such types of standards and we see no reason why there should not also be a reciprocal relationship in the evolution of these standards. For instance, the recently published international standard ISO 26000 on corporate social responsibility is intended to bring unity between different, but similar standards on social responsibility. Consumer representatives united in ISO's Consumer Policy Committee ISO/Copolco – a rather homogeneous group – initiated ISO 26001 in 2001. The drafting process started in 2005 and involved a diverse group of stakeholders, including nations, firms and research institutes, adapting the standard over time (Frost, 2011). This standard has been modified to make it more acceptable to a variety of stakeholders. For instance, industry representatives were afraid that governments would refer to this standard in future legislation so that they would be forced to meet CSR requirements. In order to get them involved it was decided from the outset that this standard should be a guidance document only, that it should not be used as a basis for certification and that it should thus not be appropriate for reference in law. This also had consequences for the contents, which was not allowed to resemble the existing management system standards. The relevance of our findings for such categories of standards is an interesting topic for further research.

Extensions of this study do not have to be confined to standards, but may also concern new product designs. The literature on new product development has emphasized the importance of flexible product designs during development as a means to adapt to changing customer requirements and new technological knowledge (Garud, Jain, & Tuertscher, 2008; Kamoche & Cunha, 2001; MacCormack, Verganti, & Iansiti, 2001). However, while this literature focuses on reactive adaptation to changes in the environment, particularly with respect to user requirements, we focus on modifications (in standards) to shape the environment and the network of actors supporting the standard. In this way, the network of supporting actors can create new markets for products in which the standard is implemented. This topic also deserves attention in research on new product development, since firms can include complementary product developers and specific user groups by adapting the product design.

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