Technology battles for complex systems: The influence of networks and standard flexibility

ABSTRACT

Most literature on standard selection focuses on compatibility standards for single products or large but single systems that are developing, such as the internet or a telecommunications network. In this study, we focus on systems that connect multiple existing subsystems and new subsystems to form a new complex system. We hypothesize that in these systems, the composition of the networks of actors that are supporting the different competing standards and the flexibility of these standards plays an important role in establishing dominance. Also, we hypothesize that both variables reinforce each other. We test these hypotheses using data that comes from a database that we have created for this study and we find support for these hypotheses.

Keywords: standards, networks, flexibility
Technology battles for complex systems: The influence of networks and standard flexibility

INTRODUCTION

Many industries are characterized by forces which lead to a single technology attaining dominance. In these industries positive direct network externalities arise where technology becomes more valuable when more people use it (Farrell & Saloner, 1985; Katz & Shapiro, 1985). Most markets in which these effects exist are ‘two sided’ in that they consist of complementary goods for which the technology defines communication (Gallaugher & Wang, 2002). Examples include the markets for VCRs (Cusumano, Mylonadis, & Rosenbloom, 1992) and video game consoles (Gallagher & Park, 2002; Schilling, 2003). When more complementary goods are available for a technology, this has a positive effect on the installed base of that technology (Schilling, 2002). These “network markets” are often path dependent meaning that random historical events can determine the outcome of a technology battle (David, 1985; David & Greenstein, 1990). The technology that eventually achieves dominance is often referred to as the “dominant design” (Abernathy & Utterback, 1978; Utterback, 1994) which is the result of an era of ferment in which different designs compete for dominance. According to evolutionary economists, the survival of a firm is the result of a process of natural selection (Arthur, 1989). Technology evolves through periods of incremental change until, at some point in time, a major breakthrough occurs in the industry. These so called technological discontinuities increase the uncertainty in the industry and usually change it considerably (Tushman & Anderson, 1986). As a result, a new technological paradigm emerges. Within a new paradigm, different technological paths can be developed, resulting in designs that compete with each other for dominance (Utterback & Abernathy, 1975).
Because the firm that establishes dominance with its technology can profit from a “winner-take-all” situation and can accrue monopoly rents with its technology (Shapiro & Varian, 1999b) it is valuable for firms to understand which factors affect the outcome of technology battles. Scholars from various fields of research have endeavored to explain the outcome of technology battles. Building on the resource based view of the firm (Penrose, 1959; Wernerfelt, 1984), scholars in the area of strategic management emphasized firm capabilities that are needed to successfully commercialize a technology. Teece (1986) uses the label complementary assets to describe factors including reputation, production capacity and distribution channels which can be exploited to reach a dominant standard (Suarez 2004). Furthermore, firms that do not invest in knowledge acquisition run the risk of being locked out of the market (Schilling, 1998, 2002). Several scholars have also focused on strategies that can be applied in network industries and that impact the expansion of an early installed base (McIntyre & Subramaniam, 2009). Willard and Cooper (1985) examine the influence of several strategic variables on survival in the TV industry and find that strategic factors influence market dominance, provided they are matched with the firm’s resources (including, its size and strength) and are effectively implemented. Various authors seem to agree on the significance of marketing communications to positively influence customer expectations regarding the standard (Besen & Farrell, 1994; Dranove & Gandal, 2003; Farrell & Saloner, 1986; Gallagher & Park, 2002). Other authors focus on the price of a standard’s implementation (Besen & Farrell, 1994; Farrell & Saloner, 1986), the availability of complementary goods (Hill, 1997; Schilling, 1999), and appropriability strategies (Bekkers, Duysters, & Verspagen, 2002; Brynjolfsson, 1996). There is an ongoing debate on the importance of timing of entry for attaining dominance (Suarez & Lanzolla, 2005). Some agree that it is better to enter early with the goal of quickly building up an initial installed base and
preempting the market while others claim that following a first mover is more beneficial since then investments and the accompanied risks can be avoided. Standardization scholars mainly emphasize technical characteristics of the standard as the main determinant of standard success. These characteristics include a standard’s quality in terms of e.g. bandwidth capacity and the compatibility that it enables (Lee, Lee, & Lee, 2003).

Scholars in the field of technology management have proposed several frameworks for standard dominance, integrating both firm and environmental level factors (Lee, O'Neal, Pruett, & Thoams, 1995; Schilling, 1998; Suarez, 2004). These scholars predominantly focus on technology battles that have occurred in single product markets, where only a small number of actors are involved (Christensen, Suarez, & Utterback, 1998; Funk, 2003; Lee et al., 1995; Schilling, 1998; Shapiro & Varian, 1999b; Tripsas, 1997). With the ongoing convergence of industries products that originate from different distinct industries are connected in increasingly complex systems. The extent to which individual firms can influence factors for standard dominance in these systems decreases. This is because an important characteristic of these systems is that a higher number of stakeholders tend to be involved (Keil, 2002). These stakeholders originate from multiple converging product markets, which greatly increases the uncertainty for the stakeholders involved (Koka, Madhavan, & Prescott, 2006). Oshri and Weeber (2006) argue that in this situation of technological convergence, it will become more difficult for firms to develop and/or promote the technology alone. For example, in the home networking industry, stakeholders originate from the information technology, telecommunications, consumer electronics, and home automation product markets, which all provide elements of the home network. When uncertainty becomes too great, firms are unwilling
to take the risks which are attached to choosing a particular standard and postpone their decision (Jakobs, 2006; Leiponen, 2008; Schmidt & Werle, 1998).

To counteract uncertainty, inter-organizational relationships may be formed (Gulati, Nohria, & Zaheer, 2000; Provan, 1982; Tushman & Rosenkopf, 1992) which can decrease the risks considerably (Gulati & Gariulo, 1999; Tidd, 1995). The literature says little about the role of networks of actors that promote standards on the chances that the standards achieve dominance. We address this gap in the literature and propose that in a complex system, the actors that support the standard and their inter-organizational relationships play an important role in whether this standard will reach dominance in the market (Kogut, 2000). A selection of researchers has paid attention to the rationale for firms to establish joint ventures (Harrigan, 1985, kogut 1988). These scholars argue that from a strategy perspective firms establish relationships with the aim of decreasing transaction costs (Kogut, 1988), enhancing their competitive position (Eisenhardt & Schoonhoven, 1996; Kogut, 1988; Porter & Fuller, 1986), and learning from each other (Hamel, 1991; Hamel, Doz, & Prahalad, 1989). These reasons will be further explored in the context of standardization. The assumption in this study is that networks of actors affect the market position of standards in two ways. First, networks of actors can provide information from diverse sources (Beckman & Haunschild, 2002). This information can be used to adapt the standard to the requirements related to different applications of the standard, facilitating the growth of its installed base. Second, networks of actors can create the collective action (Marwell & Oliver, 1984; Smith, 1976) required to create a strong market position for a standard. If all members of a network adhere to a standard in the products they produce or apply, the installed base of that standard will grow.
Furthermore, an understudied aspect of a standard’s technical characteristics concerns its flexibility or the extent to which it can be adapted to enable communication between different products. Technology management scholars have argued that in turbulent environments with high levels of uncertainty, firms should adopt a flexible new product development process (Iansiti, 1995; Thomke & Reinertsen, 1998). Similarly, in a situation where systems are rapidly increasing in complexity it can be argued that it is important for a standard to change along the way. So, the objective of this study is to gain a better understanding of the influence of the characteristics of the network of a standard and the flexibility of the standard on the chances that standards achieve dominance in the case of complex systems. We define a complex system as one in which there are multiple interactions between many different components (Mitchell & Singh, 1996) that can be systems in their own right (Simon, 1962; Soh & Roberts, 2003) and that originate from multiple converging product markets (Baker, Green, Einhorn, & Moon, 2004; Duysters & Hagedoorn, 1998). Such systems usually consist of established systems that all have their own installed base. Examples of complex systems include home networks, office building automation systems, airport systems, and the inland transportation system for maritime containers. In this study we focus on the home network.

In Section 2, we will use concepts from social network literature and standardization literature to come to a definition of a network of a standard. In Section 3, we will present hypotheses about the relationship between the composition of the network of a standard and the flexibility of the standard on the chances that the standard achieves dominance; and between the flexibility of the standard and the diversity within the network of a standard. In Section 4, we will present the methodology of this study. In Section 5, we will present the data. Finally, in Section 6, we will provide a conclusion and discussion.
NETWORK OF A STANDARD

A social network can be defined as consisting of two or more nodes that are connected to each other through one or more ties (Wasserman & Faust, 1994). A tie establishes a relationship, which can be formed by more or less regular communication between nodes. The nodes range from individuals to firms. When actors belong to groups of actors two types of modes exist: actors and ‘events’ (Wasserman & Faust, 1994). An event is a social collectivity in which two or more actors participate, such as a meeting or an activity. In social network literature, these networks are called two mode affiliation networks (Scott, 2000). In this study, following Leiponen (2008), the concept of a two mode affiliation network will be applied to the area of standardization. We will define the actors and the events with which the actors are affiliated.

Actors are the companies, governmental institutions (other than governmental standardization organizations, academic institutions, and nonprofit institutions) that have in common that they develop, maintain and/or promote the same standard. Events are SO, which, in terms of network theory, can be defined as connections between two or more actors with the aim of the mutual development, maintenance, and/or promotion of the standard (Mulder, 1992 as cited by Egyedi, 2003)). Examples of SOs include consortia, formal SOs, sectoral SOs, governmental SOs, and professional SOs (De Vries, 1999, pp. 18-21). In an SO the vast majority of the actors support the standard that is developed and or promoted by that SO (in exceptional cases, an actor may join to counteract a standard (Nickerson & Zur Muhlen, 2006)). We can thus define the network of a standard as the set of actors that are involved in an SO, which serves the objective of developing, maintaining, and/or promoting that standard. In this study, we focus on the consortium which can refer to:
• An organization that performs standards-related activities without actually developing standards (Weiss & Cargill, 1992), such as a promoting consortium that either promotes consensus standards or de facto standards.

• An organization that actively develops new technologies that are intended to form the basis for either de facto or consensus standards, such as a development consortium that can develop options for consensus standards to be evaluated and possibly approved by formal standardization organizations. These consortia also include organizations that develop de facto standards (in which case promotion and maintenance of the standard is left to other SOs).

• An organization that both develops and promotes de facto standards.

• A standardization alliance, which is a contractual agreement (Burgers, Hill, & Kim, 1993) between two or more actors to jointly sponsor a technological standard (Hill, 1997) with the aim of making this standard the de facto standard in the market. The main distinction between alliances and other types of consortia is that the latter are organized in a hierarchical way.

THEORY

In this section, we place this study in the context of existing theoretical and empirical studies that study the impact of business networks on standardization outcomes. Furthermore, drawing from the present literature, we develop testable hypotheses.

Standardization scholars have thoroughly emphasized the influence of other stakeholders in the standards battle. Often, stakeholders other than the group of standard supporters can be influential. Firms can establish cooperation with these stakeholders, thereby decreasing the
uncertainty that exists for each of the firms (Gulati & Gariulo, 1999). The influence of cooperation on the establishment of a dominant standard has been illustrated in multiple examples of standards battles. One form of cooperation is a licensing agreement, which can help build an installed base quickly and can increase the acceptance of a firm’s standard. This was one of the reasons behind the success of Matsushita in the video standards battle (Cusumano et al., 1992) and Microsoft in the operating systems battle (Wonglimpiyarat, 2005). Licensing agreements have also played a role in the workstations industry (Garud & Kumaraswamy, 1993) and the video game industry (Gallagher & Park, 2002). When firms license their technology to other firms, they can acquire additional distribution channels and thus increase their installed base (Bekkers et al., 2002). Another form of cooperation is inter-organizational relationships. This includes vertical relationships between buyers and suppliers, horizontal relationships between competitors, and diagonal relationships between firms operating in different product markets (Nooteboom, 1998). In the case of digital recording technology, two competing standards existed: DCC (Philips) and Minidisc (Sony). Since the consumer waited for one of the standards to become dominant, neither standard has become dominant. In another situation, Philips and Sony worked together and developed one standard which achieved dominance: the compact disc (Hill, 1997). A special kind of inter-organizational relationship is that between a firm and a manufacturer of complementary goods (Cusumano et al., 1992; Khazam & Mowery, 1994; Willard & Cooper, 1985). An advantage of inter-firm relationships is that firms can learn from the actors with which they are connected (Schmidt & Werle, 1998). For complex systems, the advantage of cooperation is that firms can gain access to new product markets (Hagedoorn, 1993). They can gain access to complementary resources from firms in different product market
and learn from them. A disadvantage of joining a network is that the firm’s influence on the standardization process may decrease.

In social network literature, it is argued that the performance of actors depends on the network in which they participate (Burt, 1992, 1997; Coleman, 1988; Granovetter, 1973). Accordingly, different aspects of a network influence the performance of actors within it. Recently, social network literature has been applied to standard selection (Suarez, 2005; Weitzel, Beimborn, & Konig, 2006). We apply it to standard selection in complex systems. The strength of a relationship is determined by many constructs, such as the emotional closeness and the frequency and duration of the relation (Marsden & Campbell, 1984). One other aspect that determines the strength of relations is the amount of novel information that is communicated (Granovetter, 1983). Groups of actors that support standards that define communication in a single product market can consist of actors that all represent the same product markets. These networks tend to be dense and relations between actors are often strong. Groups of actors that support standards that define communication between different product markets can consist of actors that are active in widely divergent product markets for which the standard defines communication. If we apply Granovetter’s theory on the strength of weak ties (1973) to this situation, the relationship between firms that represent different product markets would be called “weak” in the sense that two groups of actors are connected that were otherwise unconnected. Through these relations a lot of novel information is communicated between the two groups that would otherwise be unconnected.

**Hypotheses development**
Strategy scholars increasingly recognize that a source of competitive advantages may lie in a firm’s inter-organizational relations (Dyer & Singh, 1998; Kogut, 1988). These linkages can provide firms access to needed assets (Harrigan, 1988; Nohria & FGarcia-Pont, 1991; Porter & Fuller, 1986), new markets (Hagedoorn & Schakenraad, 1990), and installed base (Langlois, 1992) and can thus be a source of value-generating resources and capabilities (Afuah, 2000; Gulati & Gariulo, 1999; Rothaermel, 2001; Van de Ven & Walker, 1984). The relationships that a firm fosters can potentially improve its strategic position (Eisenhardt & Schoonhoven, 1996; Kogut, 1988; Porter & Fuller, 1986). Some scholars perceive a firm’s network as a resource of its own accord (Afuah, 2000; Gulati, 1999) which, in social network terms, is comparable to the concept of social capital (Burt, 1997). Other scholars use the term relational capital to emphasize that the values emanates from the partnerships and not from the firms alone (Kale, Singh, & Perlmutter, 2000). Consequently, in the literature a move from a dyadic to a network level of analysis has been observed (Gulati et al., 2000). Some scholars relate the characteristics of networks and the actors involved to firm-level outcomes (Hagedoorn & Schakenraad, 1994). It has been shown that by forming networks, firms may increase their financial performance (Baum, Calabrese, & Silverman, 2000; Hagedoorn & Schakenraad, 1994; Stuart, 2000) and, ultimately their chances of survival (Baum & Oliver, 1991; Mitchell & Singh, 1996; Mitsuhashu & Greve, 2009).

Following this line of reasoning and applying it to standard selection, relations may give firms access to complementary assets (Teece, 1986) increasing the likelihood of standard dominance (Suarez, 2004). Examples of these assets include (brand) reputation (Gallagher & Park, 2002; Schilling, 2003; Shapiro & Varian, 1999a), manufacturing capability (Suarez & Lanzolla, 2005), and additional distribution channels needed to distribute the complementary goods that
implement the standard (Schilling, 2003; Wonglimpiyarat, 2005). Ensuing this argument we propose that the more firms involved in a standards organization, the higher the chance that the standard achieves dominance.

Hypothesis 1: The higher the number of firms that participate in a network of a standard, the more likely the standard will become dominant.

Relations can also provide firms with access to assets in the form of additional financial resources. When introducing a standard, financial resources can be used to compensate start-up losses (Ehrhardt, 2004); a group of standard supporters that has a higher financial strength than competitors can endure longer periods of low earnings due to low prices, as well as spend more on marketing (Schilling, 1999). Thus, we expect that the more powerful actors are involved in the network of a standard, the higher are the standard’s chances of achieving dominance (Axelrod et al., 1995). We therefore assume that the market power of the network positively influences the chances that a standard becomes dominant. We define the market power of a network as the sum of the market powers of the individual members of the network. We propose:

Hypothesis 2: The higher the market power of the network of a standard, the more likely the standard will become dominant.

Many firms form inter-organizational relationships to learn tacit capabilities (Lane & Lubatkin, 1998) or obtain knowledge that is difficult to obtain by other means (Dyer & Singh, 1998; Hamel, 1991; Kogut, 1988). One example can be found in the Canadian biotechnology industry
where start-ups allied with different firms to access their capabilities and information; the resulting diverse network increased the start-ups performance considerably (Baum 2000). The impact of network diversity on firm performance is said to be positive due to the fact that in networks that are diverse, firms will have access to more diverse information (Beckman & Haunschild, 2002); (Gilsing & Nootbeoom, 2005), which leads to greater levels of learning (Dussauge, Garrette, & Mitchel, 2000). In networks that are diverse, complementary technological capabilities can be matched (Hagedoorn, 1993). On the other hand, diversity can potentially lead to decreasing mutual understanding (Nootbeoom, Vanhaverbeke, Duysters, Gilsing, & Van den Oord, 2007), a lack of trust, and unfamiliarity between actors in the network (Goerzen & Beamish, 2005). Also, forming alliances with the aim of learning can involve considerable amounts of risk as firms might disband the alliance prematurely and apply their newly appropriated knowledge independently as was the case with many joint ventures between Japanese and US firms (Hamel et al., 1989). In fact, some scholars have described alliances as ‘learning races’ in which each partner behaves opportunistically and wants to achieve its goal of learning first (Hamel, 1991; Hamel et al., 1989). The potential opportunistic outcomes of organizational learning can be diminished if a certain amount of trust exists between the partners that are involved in the relationship (Kale et al., 2000).

The diversity of the network of a standard can be defined as the amount of different product markets that are represented in the network. For a standard to become dominant in a complex system, it is important that its network covers all product markets that are converging (Gomes-Casseras, 1994). Novel information can be gained from the different product markets that converge. By gaining access to novel information, actors can learn from each other and incorporate the novel information into the standard, thus increasing the chances that the standard
achieves dominance (Schilling, 2002). Markus (2006) has studied vertical information systems standards which connect information systems from user organizations of different structural types and proposes that collective participation of representative members is necessary to reach a standard that will meet the needs of each of these organizations.

Furthermore, when the network of the standard includes actors that represent different product markets that are converging, the potential installed base of the standard increases as it can make use of the installed base of each of the different actors that are involved. Also, by incorporating important actors from particular industries other actors within those industries may follow the important actors increasing network size and thus increasing potential installed base. We conclude that diversity is important for a standard becoming dominant. In other words, the network of a standard that connects subsystem X to subsystem Y benefits from the inclusion of manufacturers from both subsystem X and subsystem Y.

**Hypothesis 3: The more divers the network of the standard, the more likely the standard will become dominant.**

Several technology management scholars have contended that in turbulent environments with high levels of uncertainty, firms should adopt a flexible new product development process (Garud, Jain, & Tuertscher, 2008; Iansiti & MacCormack, 1997; Iansiti, 1995; Kamochê & Pina e Cunha, 2001; MacCormack & Verganti, 2003; Moorman & Miner, 1998; Thomke & Reinertsen, 1998). This may speed up development time (Eisenhardt & Tabrizi, 1995), improve product quality (MacCormack & Verganti, 2003) and project performance (MacCormack, Verganti, & Iansiti, 2001; Thomke, 1997). Flexibility facilitates the adaptation of a product to
customer requirements (Thomke, 1997). Ideally, a match with user requirements can be reached. For instance, in the internet software industry, product quality can be increased by incorporating customer feedback into the software early on in the product development process (MacCormack & Verganti, 2003). While most studies on flexibility in new product development focus on the point until market introduction we argue that it may still be important after that point. Presumably, users will preferably adopt a standard in which their requirements have been taken care of. Standardization literature addresses the topic of flexibility as well and implicitly assumes a more flexible standard adds to technological superiority and thus, ceteris paribus, to standard dominance (De Vries, 1999; Hanseth, Monteiro, & Hatling, 1996). The modification of the standard can result in an increase in technological superiority (in terms of bandwidth capacity, for instance). Ideally, the standard is adapted to the requirements of every product market involved. This can increase the installed base of the standard. Accordingly, we hypothesize that when a standard is more flexible, the chances that the standard will become dominant will increase.

**Hypothesis 4: The higher the flexibility of the standard, the more likely the standard will become dominant.**

Sometimes standards are modified with the goal of including other actors to the network of the standard. For example the French company Thomson initially did not want to support the HDTV standard since it owned to little patents in this area and therefore could not guarantee profits on the long term. However, the group of HDTV standard supporters knew that with the support of Thomson the chances that the HDTV standard would achieve dominance would
increase and therefore the group modified the standard and incorporated a French
packetswitching system that was technically inferior to the existing British system. This was
done with the goal of attracting Thomson to the group of HDTV standard supporters. (Simons
and Vries de, 2002).” By doing so the chances that the French would chose for the standard
increased considerably and that would also have a positive effect on other southern European
countries. When the standard is modified to realize communication with other systems, this
increases the compatibility that the standard enables. When a standard enables compatibility with
multiple systems (from different product markets), the actors that develop products for these
systems can choose to support the standard. This will increase the size and diversity of the
network of the standard. Thus, standards are sometimes changed to realize communication with
other systems, so to include representatives of those systems and increase the dominance of the
standard. At the same time, when those actors (representing different product markets) choose to
join the network of that standard, they will also try to change the standard to increase
compatibility with products from their own market.

Therefore, we argue that diversity and flexibility reinforce each other and a self-reinforcing
cycle arises: diversity increases the flexibility of the standard and vice versa. We hypothesize:

\textit{Hypothesis 5: the diversity of the network of a standard and the flexibility of the standard
reinforce each other}

Our hypotheses are shown in the research model in Figure 1.
METHODOLOGY

Unit of analysis

Since consortia play an important role in the outcome of standards battles, this study focuses on their role. In consortia, all actors involved are expected to have a full commitment and we can thus measure ‘involvement’ in an unambiguous way. However, the group of active members in the consortia can be much smaller than the total membership. What most of these consortia have in common is a group of actors that set the strategic objectives of the consortium. This is the highest organizational unit in the consortium (in most cases the board of directors). Usually, this unit decides about the final approval of the specifications that are drafted in the various committees and working groups. Therefore, in most consortia, these actors are the most important actors when it comes to the adaptation of the standard. By representing the consortium with this group of actors, we take into account those actors that we expect to be actively involved in the standards process. Organizations can be represented by their board of directors (see for instance Davis, 1991). Similarly, we represent SOs by their board of directors.

Data

For this study, we created a database that covers the time period from 1996 to 2006. In the database, each record represents one SO. The database contains membership information on the SOs, the actors that are members of the SOs, and the standards that are being developed, maintained and/or promoted by the SOs. Data sources that were used to construct the database include the internet pages of the different SOs being studied as well as press releases both on these and other sites, the Lexis-Nexis archives, annual reports of companies, and the Thomson one banker database of company profiles. The data is collected by performing a retrospective
search using the internet archive. The internet archive is an online library that consists of archived versions of web sites which can be freely used by researchers. In each year at multiple points in time the internet archive scans the websites for changes. By consulting the homepage of each consortium, the network could be reconstructed over time from the moment that it was founded until the moment that it was dissolved. For each year it was determined at which time the webpage was first updated and the members (of the board of directors) that were present in the network at that time were recorded in the database. When membership information from one year was not available, it was assumed that the membership did not change. We focus on the fifty-five consortia that promote home networking standards.

**Context: the home networking market**

This study focuses on the home networking market. Home networks combine components and technologies from the consumer electronics (CE) product market (such as, TV, audio and gaming consoles), the information technology (IT) product market (such as, personal computers), the telecommunications (TE) product market (such as, smart phones), and the home automation (HA) product market (such as thermostats and door chimes). Firms that are active in home networking come from each of these four product markets, making this an ideal research context.

**Variables**

**Standard dominance:** this is measured by assessing whether the SO that supports the standard still exists or not in a particular year. Firm survival is frequently used in the literature to operationalize standard dominance (Christensen et al., 1998; Suarez & Utterback, 1995; Willard & Cooper, 1985). Here, the dominance of the standard is determined by analyzing whether the organization (that promotes the standard) survives the standards battle or not. The SO does not
survive the battle when it is announced that the standard has become obsolete or that the SO was dissolved. We treat mergers of SOs as censored exits. To determine the point in time that the exit occurs, we have analyzed secondary sources in which this information is communicated (in particular news archives).

**Network diversity**: For each actor, we collect information regarding the industry in which it operates primarily. For each actor, we collect its (primary) standard industry code, which is a four digit number used to categorize actors according to the industry in which they primarily operate. This information is retrieved from the Thomson one banker database. We use that code, together with the company’s description, to determine into which of the four product markets that are converging in the home network industry the actor can be categorized. For the actors for which both the SIC codes as well as the company’s description could not be retrieved, we analyzed other sources (such as, other company reports, databases, and the internet). In total, we categorized 482 actors. Network diversity is measured by counting the number of different product markets that are represented in each of the SOs that develop, maintain, and/or promote the standard. This variable ranges from 1 (meaning that one relevant product market is represented) to 4 (meaning that each relevant product market is represented).

**Market power of the network**: This is measured by counting the annual sales of the actors. This information is also retrieved from the Thomson one banker database. This variable not only measures market power in the home networking market, but in all markets that the firm is active in. The firm can use its power in other markets to establish a dominant standard in the home networking market. Intel, for instance, can use its power in the semiconductor market to try to establish a dominant standard in the home networking market.
One way to increase the flexibility of a design is by developing multiple iterations of the design that may be new and or build upon each other (Eisenhardt & Tabrizi, 1995). **Flexibility of the standard** is measured by counting the total number of times that a new version of the standard was released since the year that the first version of the standard was released. This has been done for the time period from 1996 to 2006. Whenever it was announced in the press that a new standard specification was released, we regard this as a new version.

**Network size** is defined as the number of companies that supported the standard by, for example, adopting the standard in their products.

**Control variables:**

**Board size:** One important characteristic of networks is their size (Gilsing & Nooteboom, 2005). The more actors are involved in the network of a standard, the higher are the standard’s chances of achieving dominance (Axelrod, Mitchell, Thomas, Bennett, & Bruderer, 1995). However, if more actors are involved, the complexity of the network increases (Van de Ven, 1976). Consensus formation is negatively correlated with group size, since larger groups suffer from problems related to control and coordination (Smith, Smith, & Olian, 1994). Therefore it is assumed that board size has a negative impact on standard dominance. We measure the size of the board by counting the number of firms that sit in the board of directors of the SOs. A higher number of actors in the board will result in more communication channels making it more difficult to reach consensus.

**Timing of entry:** This can be essential for achieving dominance in a market (Kristiansen, 1998; Lieberman & Montgomery, 1998; Mitchell, 1991). In most studies, it is argued that early entry can create an installed base and contribute to dominance (Katz & Shapiro, 1985;
Lieberman & Montgomery, 1988; Suarez & Utterback, 1995). We measure the timing of entry by looking at the moment in time that the SO was formed.

**Method**

To test the first three hypotheses, we use logistic regression on the likelihood that an SO will exit the home networking industry in any given year (Christensen et al., 1998). We regress the event indicator on the time indicators (D1 trough D11) and the predictor variables. For every record in the dataset, the event indicator takes on either the value 0 (the SO still survives in that year) or 1 (the SO did not survive in that year). In the first year of the existence of the SO the time indicator D1 is set to 1 and the other time indicators are set to 0; in the second year of its existence, the time indicator D2 is set to 1 and the other time indicators are set to 0, and so on. The general model used can be written as:

\[
\logit h(t_j) = [\alpha_1 D_1 + \alpha_2 D_2 + \ldots + \alpha_{11} D_{11}] + \beta_1 Diversity + \beta_2 MarketPower + \beta_3 Flexibility + \beta_4 TimeofEntry + \beta_5 Size
\]

where \( h(t_j) \) is the hazard at time \( t_j \), \( D_1 \) to \( D_{11} \) are dummy variables which refer to the time period (there are 11 time periods in the dataset), Diversity, MarketPower, Flexibility, and Size are time varying predictor variables, TimeofEntry is a time-invarying variable, and \( \alpha_i \) and \( \beta_k \) are the parameters that are estimated. This model can be fitted using logistic regression (Singer & Willett, 2003).
RESULTS

Using a person period dataset consisting of 297 records, the life table, the hazard function, and the survival function were manually computed. In Table 1, the life table describing the number of years a consortium survives for a sample of fifty-four consortia is presented.

In Table 1, the life table describing the number of years a consortium survives for a sample of fifty-four consortia is presented.

In Figure 2, the estimated hazard function and the estimated survival function are presented. To estimate standard error of the survival probabilities, we applied Greenwood's approximation (Singer & Willett, 2003 see page 350). Since standard errors cannot be trusted for any time period in which the size of the risk set drops below twenty years 8 through 11 are not interpreted. Since the estimated survival function does not reach 0.5, the estimated medium life time could not be computed, which means that less than half of the population is predicted to experience the target event by Year 8.

The hazard function is non-monotonic in that it has multiple distinctive peaks and troughs (Singer & Willett, 2003). In the first two years, hazard is zero. However, from Year 3 to Year 8, hazard increases and reaches two distinctive peaks in the fourth and the sixth year. This same pattern is also shown in the survival function, where, in the first two years, estimated survival probability is 1 (meaning that every consortium survives). In the years that follow, estimated survival probability declines to 0.5711. It seems that, ceteris paribus, in the first years of the existence of a consortium, the chances that the consortium will leave the market are low, but in the years that follow they increase.
Table 2 contains the means, standard deviations, samples size, and correlations of the variables. To test Hypothesis 4, we created a one year lag variable for both the diversity variable (diversity at t+1) and the flexibility variable (flexibility at t+1). Both correlations between diversity and the flexibility lag variable and flexibility and the diversity lag variable were positively correlated indicating support for Hypothesis 4. Multicollinearity was tested for by analyzing the correlations among the variables at the median time of entry (2000) across all observations. It does not seem to be a problem.

To test hypotheses 1, 2, and 3, we performed a discrete time-event analysis. In Block 1, we enter the time dummy variables together with the control variables. In Block 2, we enter the predictor variables. When we could not retrieve an actor’s annual sales, we estimated the sales to be zero. We computed the series mean for entries that have total sales of zero. We took the natural logarithm of both sales and flexibility. This results in the two models as presented in Table 3.

A negative sign for a parameter indicates that the higher the parameter, the lower the risk of event occurrence. Its magnitude estimates the size of the vertical differential in logit hazard corresponding to a 1-unit difference in the parameter. In Model 2, the timing of entry parameter is positive (p = .040), indicating that the earlier the timing of entry, the lower the risk of event occurrence. Board size is insignificantly related to the risk of event occurrence. The diversity parameter is negative (-.92). The Wald based chi square hypothesis test for diversity provides a value of 4.09, which is significant at the .04 level. Thus, the diversity estimate is significantly
related to SO survival (meaning that higher values of diversity will result in decreased hazard of event occurrence, thereby increasing the chances of survival). Thus, in every year from 1996 to 2006, consortia that are more diverse are less likely to leave the industry than consortia that are less diverse. Antilogging the diversity estimate yields an estimated odds ratio of .40 with a confidence interval of .16 to .97. Thus, for every one unit increase in diversity, the estimated odds that a consortium leaves the market are 60 percent lower. This provides strong support for Hypothesis 1. We reject Hypothesis 2 because it appears that market power is insignificantly related to SO survival. The flexibility parameter is negative (-2.35) and significant (Wald based chi square hypothesis test is 4.02, p = .05). The flexibility parameter is also quite strong since antilogging yields an estimated odds ratio of .095, with a confidence interval of between .01 and .95. Thus, we find strong support for Hypothesis 3.

Model B has a higher deviance, indicating that model B is a better fit when compared to the baseline model. Also, the variables in the model explain a lot of the variance in the data (R²: .695) signifying a good fit.

For sixteen SOs, we could not retrieve data concerning the flexibility of the standard. This was mainly due to the fact that for some proprietary standards, data concerning the flexibility of the standard was only available for members of the consortia. Excluding these SOs from our account reduces our sample size from 296 to 217. We performed a separate analysis on the full dataset without the flexibility variable. In this model the magnitude of the diversity estimate is similar, but its significance increases from .05 to .02.

**CONCLUSION**

In this study, we have concentrated on standardization processes where different product markets converge. We have argued that the resulting system that can be realized is complex due
to the different established subsystems that are connected within the system. We developed a model for the influence of the characteristics of the networks of firms and the flexibility of the standard, on the chances that it becomes dominant. We have studied the dynamics of the network of actors per standard. We have tested our hypotheses by developing a database using secondary sources. Our study bridges the literature on firm networks and standardization processes. We have found that the diversity of the network of the standard has a significant positive effect on the chances that the standard achieves dominance. Thus, it appears that when standards are supported by more diverse networks in terms of product market representation, the chances that these standards reach dominance will increase. Further, it appears that if the standard is more frequently adapted to user requirements the chances that it will become dominant increase. It would seem that a standard should not be too 'standard', but should be flexible enough so that it can be changed to realize communication with other systems, resulting in a higher chance that the standard achieves dominance. Finally, it appears that flexibility and network diversity reinforce each other. Thus, it appears that when a standard is more flexible, the network of that standard can become more diverse and vice versa.

One limitation concerns the operationalization of some variables. For example, we operationalized standard dominance in terms of the survival of the SO. In literature, standard dominance is often operationalised by market share per standard (Majumdar & Venkataraman, 1998; Mitchell, 1991; Tegarden, Hatfield, & Echols, 1999; Wade, 1995). To measure market share one could count the number of products that adhere to the standard and divide this by the total number of products in the applicable product category. However, in many cases, we do not know in which context the products are used. Consider a company that is active in the consumer electronics industry and supports the WIFI standard. It could use this standard in its TV sets in
order to realize communication with PCs in the home. Alternatively it could use this standard in its DVD player to realize communication with the TV set. In the first situation, the company uses the standard to realize a home network; whereas in the latter situation, the company does not.

Another difficulty with respect to market share is that it is difficult to measure, since the list of companies that supports the standard is not always available. We measured flexibility by counting the number of new versions of the standard that were released. It should be noted that when a new version of a standard is released, this does not always mean that the contents of the standard have been changed. Therefore, one should look at whether changes have actually been incorporated into the standards. However, since most of the time specifications are not freely accessible, this was impossible to do. However, we have analyzed a sample of the specifications that were available and in most cases the different versions of the standard differed considerably.

Finally, we measured timing of entry by the date at which the SO was formed. Almost in every case, the date at which the standard is released is the same as the date at which the SO is formed. For instance, the WiFi alliance was formed in 1999 and the 802.11a standard was introduced in the same year. However, in some cases the year that the SO is formed is not the same as the year that the standard was introduced (and there are one or two years in between).

Relationships can differ with respect to their degree of formality (Van de Ven, 1976) where personal relations are less formal then corporate relations for instance (Burt, 1997; Marsden & Campbell, 1984). A limitation of this research is the fact that those relations that have a small amount of formality tend to be difficult to measure whereas these relations could play a prominent role in reaching a standard for complex systems. An example is the battle for the standard for next generation DVDs, where Microsoft Chairman Bill Gates met with Sony’s CEO.
Howard Stringer and discussed Microsoft’s possible adoption of the Blu-ray standard for high definition DVD (Porto, 2005).

An area for further research is the importance of the power of individual actors over other actors within the network. This can be either in the form of mere influence to domination of one actor over another (Knoke, 1990). Sometimes in networks supporting standards one actor controls the other actors. The advantage here is that decisions can be taken quickly. It would be interesting to study whether this situation is preferred over a situation where actors have more equal roles. Future research could fruitfully examine this subject.

Finally, we have focused in this study on home networking standards. Further research could try to replicate these findings in other areas where standards compete for dominance. As such the generalizability of our findings can be assessed.

References


Hagedoorn, J. & Schakenraad, J. 1990. inter-firm partnerships and cooperative strategies in core technologies. In C. Freeman & L. Soete (Eds.), *New Explorations in the Economics of Technological Change*.


FIGURE 1:
Research model

Dit moet het plaatje worden:
FIGURE 2:
Estimated hazard functions and survivor functions

Years since establishment of standard organization

Estimated hazard probability

Estimated survival probability

Years since establishment of standard organization
<table>
<thead>
<tr>
<th>year</th>
<th>time interval</th>
<th>Standards organizations at the beginning of the year</th>
<th>Standards organizations that experienced the event during the year</th>
<th>Censored standards organizations at the end of the year</th>
<th>Estimated hazard probability</th>
<th>Standard error</th>
<th>Estimated survivor probability</th>
<th>Term under the square root sign</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(0,1)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>(1,2)</td>
<td>54</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>(2,3)</td>
<td>52</td>
<td>0</td>
<td>13</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>(3,4)</td>
<td>39</td>
<td>3</td>
<td>5</td>
<td>0.08</td>
<td>0.04</td>
<td>0.92</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>4</td>
<td>(4,5)</td>
<td>31</td>
<td>3</td>
<td>0</td>
<td>0.10</td>
<td>0.05</td>
<td>0.83</td>
<td>0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>5</td>
<td>(5,6)</td>
<td>28</td>
<td>2</td>
<td>4</td>
<td>0.07</td>
<td>0.05</td>
<td>0.77</td>
<td>0.01</td>
<td>0.07</td>
</tr>
<tr>
<td>6</td>
<td>(6,7)</td>
<td>22</td>
<td>3</td>
<td>0</td>
<td>0.14</td>
<td>0.07</td>
<td>0.67</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>(7,8)</td>
<td>19</td>
<td>2</td>
<td>5</td>
<td>0.11</td>
<td>0.07</td>
<td>0.60</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>8</td>
<td>(8,9)</td>
<td>12</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.60</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>9</td>
<td>(9,10)</td>
<td>9</td>
<td>0</td>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.60</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>10</td>
<td>(10,11)</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.60</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td>11</td>
<td>(11,12)</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.60</td>
<td>0.02</td>
<td>0.09</td>
</tr>
</tbody>
</table>
### TABLE 2
Descriptive statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>N</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Board size</td>
<td>10.10</td>
<td>5.94</td>
<td>289</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Timing of entry</td>
<td>1997.2</td>
<td>4.38</td>
<td>289</td>
<td>-</td>
<td>0.28**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Diversity</td>
<td>2.55</td>
<td>1.06</td>
<td>289</td>
<td>0.47**</td>
<td>-0.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Market power</td>
<td>25.84</td>
<td>0.87</td>
<td>289</td>
<td>0.39**</td>
<td>-0.06</td>
<td>0.42*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Flexibility</td>
<td>1.03</td>
<td>0.87</td>
<td>217</td>
<td>0.19**</td>
<td></td>
<td></td>
<td>0.24*</td>
<td>0.17*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Diversity lag</td>
<td>2.58</td>
<td>1.06</td>
<td>234</td>
<td>0.44**</td>
<td>-0.05</td>
<td>0.89*</td>
<td>0.40*</td>
<td>0.22*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Flexibility lag</td>
<td>0.97</td>
<td>0.86</td>
<td>178</td>
<td>0.20**</td>
<td></td>
<td></td>
<td></td>
<td>0.23*</td>
<td>0.17*</td>
<td>0.93*</td>
</tr>
</tbody>
</table>

** p < 0.01 * p < 0.05 level
### TABLE 3
Results of fitting two discrete-time hazard models to the data

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing of entry</td>
<td>.13</td>
<td>.41*</td>
</tr>
<tr>
<td>Board size</td>
<td>-.17</td>
<td>.08</td>
</tr>
<tr>
<td>Diversity</td>
<td>-.91*</td>
<td></td>
</tr>
<tr>
<td>Market power</td>
<td>-.82</td>
<td></td>
</tr>
<tr>
<td>Flexibility of the standard</td>
<td></td>
<td>-2.35*</td>
</tr>
</tbody>
</table>

**Goodness-of-fit**

| Deviance (-2LL)               | 53.03   | 42.86*  |
| # parameters                  | 13      | 16      |
| N                             | 217     | 217     |
| R²                            | .68     | .69     |

**Wald Based Hypothesis Test**

| Ho: | β diversified = 0 | 4.08* |
| Ho: | β Market power = 0 | 1.50  |
| Ho: | β Flexibility of the standard = 0 | 4.02* |

* p < .05, † in this model the 11 time dummies were included