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WITH WHOM DO TECHNOLOGY SPONSORS PARTNER DURING TECHNOLOGY BATTLES? SOCIAL NETWORKING STRATEGIES FOR UNPROVEN (AND PROVED) TECHNOLOGIES

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Abstract

The academic literature on technology standards has grown rapidly in the last three decades. An intriguing thread in this literature studies social networks? influence on standards setting processes. Surprisingly little attention has been given to the potential for technology sponsors to use social networks strategically, to influence the emergence of de facto standards. We theorize that sponsors choose alliance partners according to the partner?s location in industry wide social networks, and that the network position which enhances an alliance candidate?s attractiveness depends upon the sponsored technology?s stage of development. We hypothesize that sponsors of technologies that are early in their development choose partners to create multiple points of contact between previous and potential adopters, called wide bridges. Redundant ties can foster the broad acceptance of a new technology that is essential to drive its diffusion. Sponsors of more developed technologies can rely on a sparser network of ties to activate peer-to-peer diffusion. In line with our predictions, we found that during the battle to establish 2G wireless standards, Qualcomm, sponsor of the unproven CDMA technology, formed alliances that conformed to a wide bridge pattern, while Ericsson, sponsor of the proven TDMA technology, formed alliances consistent with a peer-to-peer pattern of diffusion.

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INTRODUCTION

An impressive body of work examines battles for dominance between competing technologies. This work highlights the need for sponsors of new technologies to enlist the support of other actors to promote their technology in order to accelerate its diffusion (Rosenkopf and Padula, 2008, Suarez, 2004; Narayanan and Chen, 2012). Key influencers, including trade associations, regulatory agencies, opinion leaders, and standards committees, can tilt a battle in favor of a technology by certifying its claims of superiority (Rosenkopf and Tushman, 1998; Dokko, Nigam and Rosenkopf, 2012). A sponsor that lacks these endorsements can seek to directly affect adopters' appraisals of its technology through media campaigns and promotional offers, or by increasing access to its technology (Varian and Shapiro, 1999; Birke, 2009; Boudreau, 2010). However, the relevance, and hence efficacy, of these tactics may depend upon which phase a technology battle has reached (Bekkers, 2001; Suarez, 2004).

Prior work highlights that both the level and kinds of uncertainty that technology sponsors and potential adopters must resolve change as a battle progresses from an early phase of market creation and design competition to later phases when a dominant design emerges (Tushman and Anderson, 1986; Kaplan and Tripsas, 2008). A technology battle transitions to a new phase as milestones are attained, such as the production of the first prototype or launch of the first commercial product (Suarez, 2004). Milestone achievements signal that certain kinds of uncertainty have been resolved and this can raise interest in the market and trigger new competitive responses (Bekkers, 2001). At the same time, within any given phase, competing sponsors may have generated different degrees of market acceptance and evidence that their technology will function as claimed. Researchers have paid little attention to how this difference might affect sponsors' strategies for promoting their technologies. We propose that a technology's stage of development will influence its sponsor's strategy for securing adoption and accelerating diffusion.

Specifically, we propose that, during design competition, when sponsors seek to demonstrate the unique advantages of their technology, the sponsor of the less developed technology will use social networks differently than will the sponsor of the technology that is better developed. We define a technology's stage of development in terms of how widely understood it is among a population of potential adopters. Technologies that use unfamiliar approaches to deliver the function in question are earlier in their development cycle, as compared to technologies that employ familiar approaches. We argue that the contagion process which drives a technology's diffusion is affected by this difference: the less shared knowledge potential adopters have, the less susceptible they will be to the influence of their peers. Instead, diffusion will entail complex contagion, in which potential adopters decide how to respond to a less developed technology only after exposure to multiple different prior adopters (Centola and Macey, 2007; Centola, 2010).

Based on this, we theorize that a sponsor of a less developed technology will seek to create multiple points of contact, within the population of potential adopters, between its current and potential alliance partners, , forming the wide bridges necessary to accumulate acceptance of their technology. By contrast, a sponsor of technology that is familiar to potential adopters can expect singular contact with its alliance partners to drive peer-to-peer diffusion, and thus will form few redundant ties.

We investigate whether these hypotheses are borne out in the second generation (2G) wireless standards battle in the U.S. market. The transition from 1G analog voice transmission to the 2G digital technologies could be viewed as a discontinuous technological change. We specifically focus on alternate means of sharing the radio frequency spectrum during the 2G design competition. The primary contestants for this function in the U.S. market were time division multiple access (TDMA) and code division multiple access (CDMA). CDMA was viewed as a larger departure from the 1G technology used to share the radio spectrum: frequency division multiple access (FDMA), than was TDMA (Marx, Gans, and Hsu, 2014; Calhoun, 1988). FDMA shared the radio spectrum by assigning calls to separate radio frequencies to each user. TDMA split each frequency channel into multiple time slots that could be allocated to different users, allowing them to take turns using a channel. CDMA shared each frequency channel simultaneously with multiple users by allocating unique codes to each user. TDMA could be layered on top of FDMA, as part of the digital AMPS (D-AMPS) 2G wireless system. In addition, whereas CDMA was first commercially launched in December 1995, TDMA achieved this milestone in 1991. Hence, in this battle, TDMA was further along in its development than was CDMA.

Consistent with our expectations, Qualcomm, sponsor of the less developed CDMA technology, formed alliances consistent with the wide bridge pattern, while Ericsson, sponsor of the more developed TDMA technology, formed alliances consistent with the peer-to-peer pattern. We also observed that as uncertainty about CDMA dissipated and the technology began to diffuse, Qualcomm started to shift from a wide bridge to a hybrid strategy, incorporating both wide bridge and peer-to-peer partnerships.

Our study makes two contributions to the literature. First, we extend the literature on technology standards battles by identifying two distinct strategies that sponsors can use to influence adopters and drive diffusion through social networks, and by theorizing that sponsors will emphasize the strategy that is consistent with their technology's stage of development. The importance of alliance partners in technology battles has been noted (Rosenbloom and Cusumano, 1987; Rosenkopf and Padula, 2008), but few studies have not examined whether sponsors choose partners in a discriminating way. Varian and Shapiro (1999), for instance, distinguished standards battles according to whether dueling technologies are backward compatible with current technologies, but did not address whether sponsors should deploy distinctive tactics to accommodate differences in compatibility. Research on technology diffusion has long recognized the important role that social networks play in spreading the information and triggering behaviors that drive adoption but tends to describe and explain the different diffusion patterns, rather than sponsors' strategies for affecting them (Geroski, 2000; Rogers, 1995; Watts and Strogatz, 1998; Greve, 2009).

To the social networks literature, we contribute by explaining how a technology's stage of development may influence the susceptibility of its potential adopters to peer influence, and thereby the efficacy of alternative strategies for diffusing new technologies. Building on the concept of contagion, social network research frequently assumes that simple contact is sufficient for information to diffuse throughout a network of connected actors (Phelps, Heidl, and Wadhwa, 2012). The possession of better, more, or unique information may be sufficient to affect an actor's decisions or task performance (Burt, 1983, 1987), but a singular contact with another actor may not be enough to induce a change in behavior, particularly if there is risk (Morris, 2000). Centola and Macey (2007) refer to instances where multiple exposures are necessary to persuade an actor to adopt a new practice or technology as a complex contagion. We theorize how the stage of a technology's development relates to potential adopters' susceptibility to peer influence and therefore to the type of contagion likely to propel its diffusion.

TECHNOLOGY BATTLES AND SOCIAL NETWORKS

Design Competition

Novel technologies emerge as new solutions to particular problems and progress through fairly predictable stages of development as their commercial viability is tested (Roberts, 1997; Suarez, 2004). Once proof that a technology can operate as conceptualized has been obtained, its sponsor must then demonstrate that it can be economically developed and produced on a large scale and that a sufficient number of customers will adopt it (Bekkers, 2001; Calhoun, 1988). Technologies that are further along in this development cycle are more widely understood by their prospective adopters. However, the transition from proving technical feasibility to developing the market is not necessarily a linear or sequential progression. Particularly when there is a possibility that one technology could dominate the market, the battle for adopters tends to begin without conclusive evidence that a technology will work as promised in the field (Arthur, 1989; Suarez, 2004). Technology sponsors engage in a design competition to persuade potential adopters that their technology is superior (Tushman and Anderson, 1986; Murmann and Frenken, 2006).

In Tushman and Anderson's (1986) model, competing designs are variants of the discontinuous technology and as such are often represented as competing on equal footing during this stage of a technology battle. However, design competition can occur between technologies that differ in important ways, such as in their novelty (Das and Van de Ven, 2000), the degree to which they are backward compatible with prior technologies (Varian and Shapiro, 1999), and in their stage of development – our focus. When technologies at different stages of development battle the sponsor of the less developed technology is likely to have a tougher time persuading potential adopters that it offers the better solution, not only because it has a shorter track record, but also because adopters may not understand how to appropriately appraise it (Garud and Rappa, 1994; Christensen, 1997).

A key challenge for sponsors during design competition is to demonstrate the unique advantages of their technology over designs that have made different performance trade-offs. The competition between the 2G technologies vying to dominate the US wireless communications market was typical in this regard: there was substantial uncertainty about which technology offered the greater overall benefits to the majority of adopters. The market for wireless communications was first established in the early 1980s with the advent of the analog 1G wireless technologies and it was still a new market at the time of the 2G battle. Of almost 100 million US phone lines in 1985 only 340 000 were cellular[1]. As demand for wireless grew, it was clear that carriers needed technologies that could make more efficient use of the available radio frequency spectrum. However, it was unclear which technology was up to the task, in part because the technologies were at different stages of development but also because there was uncertainty about how quickly demand would grow and what the precise needs of the end users would be. For example, how important would the quality of calls be and to what degree would cell phone users trade-off sound quality with ease of roaming or the frequency of dropped calls? Would users view security, which wasn't present in 1G, as important?

From 1985 on, many papers comparing the merits of CDMA versus TDMA were published and these illustrate the challenge of clearly discerning which technology was superior (e.g. see Jung, 1993; Falconer et al, 1995; Hemphill, 2009). Although researchers reported a number of benefits of CDMA, including superior capacity, flexibility, and immunity to multi path fading, the main enemy of radio mobile communication, other concluded that CDMA's potential advantages over TDMA/FDMA came at the cost of implementation complexity (Gilder, 2000; Bekkers, 2001). Cost was a particularly salient issue for wireless carriers, most of whom had lost money on their 1G services (Calhoun, 1988). Some complained that the advantages of CDMA had been presented qualitatively rather than quantitatively, and noted that multiple variables could affect how its performance would degrade as the number of subscribers to a cellular network rose, making it difficult to anticipate how CDMA would perform in practice (e.g. Kohno et al, 1995). Discussions about their relative advantages and disadvantages sometimes resembled a religious war, with CDMA's detractors claiming that it would 'violate the laws of physics' and accusing Qualcomm of faking its demonstration (Brodsky, 2008, p. 199). Marx et al (2014) characterized CDMA as having been "controversial" at the time – noting that

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[1] In 2012 there were 139 million landlines and 310 million cellular phones in use.

handling multiple calls on the same frequency simultaneously as opposed to sequentially stacking calls, went against the "prevailing protocol, TDMA." Substantial skepticism was voiced in the popular press as well[2].

Sponsors of unproven technologies need to provide potential adopters with the assurance that their technologies can live up to their claims (Das and van de Ven, 2000). We propose that astute sponsors will seek out adopters whose positions in the social network of other potential adopters makes them particularly instrumental in fostering the diffusion of their technology.

Social Networks and Technology Adoption

Firms rely on social networks to acquire and validate information, reduce uncertainty, and to make sense of unfamiliar situations, including choosing which technology to adopt (Coleman et al., 1966; Granovetter, 1973; Rosenkopf and Padula, 2009). In fact, social networks can exert a stronger influence on adoption decisions and diffusion patterns than do objective measures of the value provided by competing alternatives – such as the size of the installed base or the level of performance (Suarez, 2004; Lee et al. 2006; Tucker, 2008; Birke, 2009). Studies suggest that social influence is most crucial when potential adopters are ill-informed about the way a technology is perceived by others or are uncertain about its benefits (Kraut et al, 1998; Bandiera and Rasul, 2006; Centola, 2010; Peng and Mu, 2011; Karsai et al, 2014). This situation is characteristic of design competition, when what constitutes good performance is subjective or vague, or when the value of a technology hinges upon its adoption by others. During this stage of a technology battle, each adoption supports the credibility of a technology's claims over competing designs. However, the degree to which cumulative adoption propels a technology's diffusion through social networks depends upon the type of social contagion that can transmit it.

Social Contagion and Diffusion Strategies

Social contagion refers to the spread of information, beliefs, technologies, and behaviors through social contact (Burt, 2003). While the mechanisms underlying transmission can vary, contagion originates when an

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[2] "In early 1989, when Jacobs Irwin, Qualcomm CEO, first approached wireless carriers to pitch CDMA, no Las Vegas bookie would have given Qualcomm any odds of success. AT&T, Motorola, and others had already opted for the so-called TDMA (time division multiple access) digital standard" (Nee and Chen, 2000).

"activated" node in a social network comes into contact with a susceptible node (Centola and Macy, 2007). In the context of disease transmission, activated nodes are actors that have been infected. With respect to technology diffusion, activation could take several forms, including a commitment to help develop a sponsor's technology or to incorporate the technology into relevant products. Activation could also indicate that an actor understands a sponsor's technology to a greater degree than does the average actor in the adopter network, possibly because it has gained some experience using it or has had extensive conversations with the sponsor. Actors are susceptible to the influence of their peers if they are ready to learn more about the technology and on that basis to make a decision regarding whether or not to adopt it (Centola, 2010).

In prior work, social contagion has been modeled using activation thresholds to represent the susceptibility of actors to the influence of their peers (Granovetter, 1978; Schelling, 1978). Specifically, a threshold is the number of activated contacts that are needed for an unactivated focal actor to become activated. Both direct and indirect contact can lead to activation and spread information and behaviors throughout a social network, but the range of potential activation thresholds is large (Strang and Tuma, 1993). A simple contagion is passed on through singular contact between activated and unactivated nodes in a network (Burt, 1993). Collectively, such peer-to-peer influence can create a domino effect and quickly diffuse a new idea or technology to a social network (Watts, 2002; Watts and Dodds, 2007). By contrast, complex contagions only diffuse through wide bridges, i.e. as each unactivated node is exposed to several different activated nodes (Centola and Macey, 2007).

This distinction has a pivotal effect on the rate at which diffusion occurs through social networks and on the kinds of ties that can accelerate or derail diffusion (Centola and Macey, 2007). We expect the distinction to be especially salient during design competition when sponsors may need to appeal to adopters differently, according to the stage of their technologies' development. Sponsors that appreciate this could form alliances that contribute to their technology's diffusion.

Simple Contagion and Peer to Peer Diffusion

Simple contagions can diffuse from peer to peer, because a singular contact with an activated node is sufficient to pass on the information needed to affect the unactivated node's decisions or behaviors (Angst et al., 2010). The more fully developed is a technology, the greater is the evidence regarding whether and how it works and what benefits it is capable of delivering to its users. In an objective sense, then, uncertainty about the advantages and disadvantages of a technology are reduced as it is developed. Certainty reduces the need for collective sense making to evaluate a technology. Potential adopters are also likely to be more aware of the better developed technology, for which information would have had more time to leak from or to be shared by its sponsor. As a result, potential adopters might require less validation of the information they receive about the technology from their peers. Prolonged exposure to a technology can also create the perception that it is a viable solution, reducing adopters' need for affirmation from their peers (Kraut et al, 1998). These forces make it easier for actors to communicate about a technology as it becomes better developed and to derive meaningful insights from simple contact. In this way, potential adopters grow more susceptible to peer influence as a technology becomes more familiar to them.

Watts and Dodds (2007) have argued that when adopters are ready to be influenced, contact with any prior adopter is sufficient for a technology to diffuse. Their work challenges the long held notion that diffusion tends to occur faster through influentials - actors that exert an extraordinary influence on the decisions of others (Katz and Lazarsfeld, 1955; Merton, 1968). Watts and Dodds (2007) simulated a large variety of network structures in order to assess when those actors with disproportionate influence on others are responsible for triggering massive cascades of adoption. While they found that in some situations, influentials accelerate diffusion, when activation thresholds are low, diffusion occurred as or more quickly through peer-to-peer contact. Further, they show that when this contact comes through weak ties – which bridge a long distance between different clusters in a network, very few ties are needed to accelerate diffusion (Watts and Strogatz, 1998;). Abrahamson and Rosenkopf (1997) refer to a similar concept, a boundary weaknesses, which occurs when potential adopters who are predisposed to adopt an innovation have a single tie to another potential adopter.

Empirical evidence supports the power of peer-to-peer diffusion. In experimental work, Salganik, Dodds, and Watts (2006) found that social influence, exerted through anonymous contact with peers determined which songs became hits. Trusov, Bodapati, and Bucklin (2010) found that in an Internet community, most people were influenced by a few others and that a small number of people have a disproportionate influence - but these were not necessarily the hubs of the network. This research suggests that, if a technology can diffuse via simple contagion, a sponsor can accelerate its diffusion by forming alliances sparsely throughout the network of potential adopters. Each alliance activates a node in the network of potential adopters, by signaling to others that it has made some degree of commitment to the sponsor's technology and by affording its firsthand access to information about the technology. Since the sponsor's alliance partner (i.e. the activated node) can influence its direct and indirect ties through simple contagion, a sponsor does not need to form redundant ties to other actors to activate them. Based on this, we hypothesize:

Hypothesis 1: A sponsor of a proven technology will form alliances consistent with a peer-to-peer diffusion strategy.

Complex Contagion and Wide Bridge Diffusion

Centola and Macey (2007) argue that not all contagions are simple. Rather, when actors are exposed to risk or uncertainty, or substantial cost is involved, potential adopters may require multiple independent exposures to activated peers before they understand the issues at hand or are ready to make a choice. Technologies that are earlier in their development cycle and hence unproven are more likely to diffuse through complex contagion, for several reasons (Coleman et al, 1966). Adopting an unproven technology is riskier as it might ultimately fail to work as promised, or the market for it may not develop. Moreover, potential adopters must process information that is complex, unfamiliar, and has not been widely validated, in order to assess these risks and compare them against a technology's potential. This will likely require piecing together information from multiple contacts. Potential adopters may lack the capacity to absorb all that they need to understand about a new technology at once. Hearing about a new technology from multiple independent contacts can help to ease the absorption process, as each contact may have different facts and perspectives to offer, some of which are easier for the target to understand. Over time, users of a technology acquire common language – including concepts, performance metrics, and techniques - that aids their collective efforts to evaluate, further develop, and utilize a technology. Potential adopters lack this shared understanding of unproven technologies, limiting the meaning they derive from individual encounters with prior adopters.

Given these barriers to adoption, Centola and Macey (2007) argue that complex contagions require wide bridges for diffusion. Wide bridges are comprised of multiple local connections between activated and unactivated nodes in an adopter network, and they can play a number of roles that aid in the diffusion process. Wide bridges provide independent affirmation of the potential benefits, credibility, and legitimacy of a new technology. Multiple exposures can help to persuade potential adopters that enabling and complementary technologies, which a focal actor's products might depend upon, will be developed. Encounters with several different supporters can also foster positive expectations with regard to a technology's commercial scale. Both are needed to offset the greater risks of going with the less proven technology.

In addition to the information they acquire from social ties, potential adopters may have been exposed to information the sponsor has made public. In verbal contests between better understood and unproven technologies, the latter bears the greater burden of proof, as novel claims with regard to how and how well a technology can work are often met with skepticism (Bekkers, 2001). Credibility is likely to be a particular issue if the unproven technology is up against one that has been publicly validated or endorsed, and has more test cases in the field. Unproven technologies are not viewed as a credible option until several of an actor's direct ties have adopted it (Coleman et al, 1966; Markus, 1987; Angst et al., 2010). Social affirmation can create a perception that novel choices are nonetheless legitimate, as hearing the same story repeatedly can reduce the tendency to view surprising information as far-fetched (Centola and Macey, 2007).

This implies that a sponsor that expects complex contagions to drive the diffusion of its technology needs to find a way to build wide bridges between adopters and potential adopters. An adopter network can be visualized as a set of connected neighborhoods, or ego networks, comprised of focal actors and their direct ties. Each of an actor's direct ties could maintain ties with other focal actors and hence be a conduit for passing on a contagion. However, complex contagions can only be transmitted through wide bridges, which collectively expose nodes in unactivated neighborhoods, to what they know, believe, or have chosen to do. Wide bridges operate through dense local ties that connect neighborhoods in an adopter network. As an actor and its ties become activated, they can pass on a contagion to the unactivated neighborhoods they are connected to. Since a sponsor will not necessarily know what the threshold for activation is, especially since this can vary by actor, it has an incentive to activate as many local nodes in a neighborhood as possible. The greater is the concentration of activated nodes in one neighborhood, the higher is the likelihood that they can pass on a complex contagion to other neighborhoods in the network[3]. Further, once the contagion begins to spread, the odds that any given activated tie will form part of a wide bridge increases. Based on this, we expect that a sponsor of an unproven technology will choose to ally with firms in the adopter network that are tied to firms the sponsor already has had alliances with. Choosing alliance partners in this way increases a sponsor's opportunities to create wide bridges.

Hypothesis 2: A sponsor of an unproven technology will form alliances consistent with a wide-bridge diffusion strategy.

Sponsors might further accelerate the diffusion of their technologies by gaining the endorsement of influentials, i.e. actors that are highly visible to and respected by their peers and/or are highly central in the social networks connecting potential adopters (Coleman et al., 1966; Van de Bulte and Lilien, 2001). Scholars have argued that influentials tend to be more in touch with leading edge practices or new technologies and that firms can accelerate the diffusion of their new products, if they first win over these adopters (Weiman, 1994; Iyengar et al, 2011). Since influentials are perceived by their peers as a credible source of information, they can attenuate concerns about unproven technologies. Sponsors of well understood technologies could choose to partner with an influential actor in the adopter network, however, as Watts and Dodds (2007) demonstrate, when thresholds for influence are low, influentials exert no greater effect on the speed of diffusion than does contact with a random peer, suggests that these partnerships might be less valuable to sponsors of proven technologies. We expect that, although it is only one metric of influence, an actor's centrality in a social network is particularly relevant to sponsors of new technologies (Katz and Lazarsfeld, 1955; Merton, 1968; Podolny, 2001). Central actors can synchronize emerging understanding about an unproven technology and pass on new evidence of its merits. Therefore we expect:

H3: *A sponsor of an unproven technology will form alliances with central actors in the adopter network.*

[3] Arthur (1987) discusses five sources of increasing returns. Communication between partners is labelled "informational increasing returns" and he writes "often a technology that is more adopted enjoys the advantage of being better known and better understood. For the risk-averse, adopting it becomes more attractive if it is more widespread."

RESEARCH METHOD

Empirical Setting

To test our hypotheses, we focused on the battle to establish a standard for the second generation (2G) of mobile communications technology in the U.S. market, which took place from the mid 1980s through the 1990s. A technical standard based on TDMA was published in 1990[4] but was challenged by a second standard based on CDMA, which was approved in 1993[5] (Hemphill, 2009; Bekkers, 2001; Färjh and Wahlberg, 2014). Whereas the first generation (1G) technology transmitted analog voice signals, the 2G technologies encoded and transmitted digital signals. Mobile phone use had grown tremendously and analog systems were unable to support the volume of calls in densely populated urban areas such as New York and Los Angeles. Digital transmission offered wireless carriers and their customers several advantages over analog, making 3-10 times more efficient use of the radio frequency spectrum.

When compared to 1G technology, the 2G technology was a competence-destroying technological discontinuity for both equipment manufacturers and telephone operators (Tushman and Anderson, 1986; Dahlin and Behrens, 2005): the transmission signal changed in nature, requiring different product technology for equipment manufacturers and different process technology for phone operators resulting in an order-of-magnitude performance increase. During the 2G cycle the industry structure changed. In the late 1980s large equipment manufacturers were vertically integrated and used to provide entire systems from transmission equipment to hand sets to national phone companies. By the end of the period, in the early 2000s, as standardization of interfaces led to modularization of cellular phone systems, many newcomers, often from neighboring industries, entered by providing a single module in the system; as integrated firms divested out of some modules, becoming more specialized (Calhoun, 1988).

When the key US standards organization for 2G cellular technology, TIA (Telecommunications Industry Association), first approved a version of the TDMA standard in 1990, much TDMA-based equipment technology had been developed, tested and was close to commercial operation as TDMA was part of the

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[4] The name of this standard is IS-54 but it is also known as D-AMPS; a higher capacity version IS-136 was approved in 1994.

[5] The name of this standard is IS-95 and it commercially known as CDMAOne.

European GSM standard that had been approved in 1987 as a *de jure* monopoly standard in 17 European countries (Bekkers, 2001). In addition, the main GSMs sponsor, Ericsson, was an integrated equipment manufacturer and could provide all modules in the system. In contrast, while the untested CDMA standard managed to catch up to the technical requirements to gain approval by the TIA in 1993, it lagged behind in technical development since its sponsor, Qualcomm, was a chip manufacturer providing satellite systems for truck companies with no prior sales in the telecom industry. The first commercial test of CDMA was in South Korea who decided on CDMA as a national standard in 1993 and launched the system in 1996 (Bekkers, 2001). Despite these differences in starting conditions, the existence of more than one technical option allowed for an intense design competition stage that lasted until the next discontinuity in signal technology, 3G, was introduced.

Design competition. The 2G design competition phase is characterized by competition between the old 1G standard versus the new 2G standard, as well as competition between the two 2G versions. To facilitate moving from 1G to 2G, the earliest version of TDMA could be integrated with the FDMA analog technology. This partial backwards compatibility was of limited importance, since the gain from switching to 2G was far greater and few operators wanted the combined systems (Hillman, 2009; Bekkers, 2001). The within-standard competition was heavily focused on which of the two technologies would ultimately perform better and what performance characteristics (call capacity, cost per unit of capacity, total investment cost per cell) would sway most adopters. Most of the 2G battle existed in a state of technological ferment since both TDMA and CDMA were continuously improved upon.

For phone operators, one of the 2G standards' most attractive features was their modular structure (Calhoun, 1988; Bekkers, 2001). This meant that the operators could freely choose different equipment firms for different parts of the system. In order to provide all modules, Qualcomm had to persuade wireless equipment manufacturers to adopt their protocols; only then could cellular carriers use the 2G enabled devices to create a transmission network (Färjh and Wahlberg, 2014). Although sponsors conducted simulations and ran experiments, a technology's performance advantages could only be fully proved when manufacturers incorporated the technology into handsets, base station transceivers and controllers; cellular carriers deployed them; and customers began to use the phones on a large scale. While the standard serves as a platform attracting equipment manufactures on the one hand, and phone operators on the other, network effects were surprisingly limited in the US, since few users expected roaming (moving between service areas with different phone companies[6] (Bekkers, 2001).

Dominant design. At the end of the 2G technology cycle in 2001[7] the worldwide market share for the TDMA standard was 86% (this includes different versions in the US, the European GSM standard and the Japanese PDC standard), and the market share for CDMA was 13% (TIU, 2014). However, when we break the numbers down per geographical market, we find that the lucrative US market had a duopoly situation with respect to the dominant design, with subscribers split between TDMA and CDMA 55% and 45%.

Data Sources

We used four databases to generate the sample and main variables: the SDC Platinum database on alliances (Thompson-Reuters), Standard & Poor's Compustat for firm characteristics, the United States Patent and Trademark Office (USPTO) database for patent information, and the Federal Communications Commission, FCC, database for phone company adoption data. We used the first two databases to establish the sample and risk set. To better understand sponsor strategies we also interviewed industry participants (Färjh and Wahlberg, 2014; Joubard, 2014), read the sponsors' 10K and annual reports, studied various documents from relevant standards development organizations (primarily the TIA and CTO), as well as technical reports, news and trade journal articles describing industry activity during the 1980s and 1990s.

Establishing the sample and the risk set

We needed to create an appropriate risk set to capture whom the sponsors might seek to form alliances in order to affect the outcome of the 2G battle and also needed to establish appropriate network boundaries to capture potential partners' positions in the network of potential adopters (see Appendix A).

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[6] The main reason for avoiding roaming was the fee structure for making phone calls, with not just outgoing but also incoming calls being charged for, making customers very price sensitive and careful with where they used their phones (Bekkers, 2001).

[7] Both the TDMA and CDMA standards were updated during the 2G cycle enhancing technical performance on key factors such as call capacity.

First ee included the population of wireless equipment manufacturers, SIC 3663. Second, we included firms outside of the wireless equipment industry (SIC 3663) in the risk set and in the network of potential adopters, provided that we had evidence of their probable interest in wireless communication technologies. Thus, we included all alliances in which at least one member was from the wireless equipment industry (SIC 3663), and then examined whether any non-3663 partners were likely to have interests in 2G technologies and the capability to develop products or offer services which deploy them. Partners in the following industries were deemed to meet this criterion: wireline equipment (SIC 3661 and 3669), wireline operators (SIC 4812), wireless (cellular) operators (SIC 4813) and industries in which wireless protocols were used in complementary technologies: consumer electronics, computer, software, and automobile. Rosenkopf and Padula (2008) follow a similar process.

We included publicly traded US wireless communication firms, even if they had formed no alliances, and we included alliances with at least one US-based firm. If an alliance did not include a US-based firm, we examined whether the alliance contained partners with a geographical focus on the U.S. market. We investigated the content of every alliance deal reported in the SDC database to examine these criteria, and relied on other secondary sources to investigate firms and alliances where the requisite information in SDC was unclear.

The filtering process left us with 1213 alliances involving 736 firms. Within the alliance risk set Qualcomm formed 104 and Ericsson formed 33 alliances, during the 2G timeframe.

We used a three-year alliance window and included alliances formed since 1987, five years before the first 2G networks were in operation, to reduce left censoring. We created 11 yearly matrices (from 1990 to 2000) using UCINET 6 (Borgatti, Everett, and Freeman, 2002); each annual matrix includes alliances formed in t, t-1, and t-2.

Dependent and Explanatory Variables

Dependent variables. We estimated separate models for Qualcomm and Ericsson and created two dependent variables, one for each candidate partner. The first variable, *Qualcomm Ally*, equals 1 if Qualcomm entered an alliance with the potential partner firm *i*, during year *t*. *Ericsson Ally* captures the same information for all potential partners, but is set according to whether Ericsson formed an alliance with the firm *i*, during year *t*.

Independent variables. The variable *Wide-bridge* is a partner attribute that captures whether a potential partner helps the sponsor build a wide bridge. Wide-bridge is the fraction of a potential partner's other alliance partners that the sponsor has alliances with. A higher wide-bridge ratio means that more of a potential partner's allies have already been activated in some way, by forming an alliance with the sponsor. For example, consider a technology sponsor initiating an alliance with firm A at time *t* (Figure 1). Since the sponsor already has alliances with four of firm A's partners (firms B, C, D, E) the wide bridge ratio is 4/5=0.8, describing a wide bridge where much exchange about the sponsor's technology can occur. Qualcomm and Ericsson have separate networks captured by *Wide-bridge_Q* and *Wide-bridge_E*.

- Insert Figure 1 about here -

The variable *Peer-to-peer* denotes whether a potential partner's network position is in a clique where no one else is in an alliance with the sponsor. If a potential partner is in a not previously connected clique, this variable is set to 1; otherwise, it is set to 0. Ericsson forming alliances with a potential partner in an unconnected clique is consistent with our H2 prediction. A clique is a group where all firms have ties (alliance relationships) to each other (Kilduff and Tsai, 2003). Cliques are groups of four or more actors, and neither dyads nor triads are cliques (Wasserman and Faust, 1994; Provan and Sebastian, 1990). We used UCINET to generate firm-clique matrices and from those created dichotomous indicators for the two peer-to-peer variables, *Peer-to-peer_Q* and *Peer-to-peer_E*, indicating if a potential partner is the only sponsor-connected clique member.[8]

Assume 16 candidate firms, one technology sponsor and four cliques (Cliques 1, 2, 3, and 4) in the alliancenetwork (Figure 2). In a clique all firms have alliances with each other. Since the sponsor already has an alliance with firms B, E and I in cliques 1, 2 and 3 a sponsor seeking peer-to-peer connections are

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[8] The IV is set to 0 when a potential partner is not in a clique. This partner could be in a triad (with only 3 firms) or could be an isolate. We set an isolate/triad's value to 0 and instead control for whether the firm is an isolate or in a triad to not spuriously overestimating the effect of peer-to-peer connection on alliance likelihood.

uninterested in allying with other member of these cliques [firms A, C, D, F, G, H and J] as the sponsor already has established a connection with each clique. However, any of the firms K, L, M, and N, would be good targets for the sponsor to establish a peer-to-peer connection, since Clique 4 is unconnected to the sponsor. On the basis of this logic, firms A~J are coded as 0, whereas firms K~N are coded as 1. Although isolate firms (such as firm O and P) are also coded as 0, we use an additional variable, isolate, to control for this effect (see below).

- Insert Figure 2 about here -

Centrality measures the number of connections each candidate partner has with other actors in the overall network, divided by the total number of possible network connections, i.e. normalized degree centrality (Freeman, 1979). The more central a candidate partner's network position, the more visible and influential the candidate is with respect to technology diffusion.

Control Variables – alternative explanations

Firm-level controls. Sponsors may be attracted to more visible partners and partners with larger resource stocks. Due to data limitations we proxy for size with the variable *Public,* to indicate that a firm is publicly traded, a characteristic associated with both visibility and firm size.

We controlled for a firm's technological ability using two patent data measures. Partners with greater technological strength might be more attractive as they could help to advance the sponsors' technologies and provide more credible endorsements of the sponsor's technology. It is also likely that innovative firms are more susceptible to an unproven technology. *Firm patent stock* sums the patents a firm was granted in years t-5 to t-1 prior to the observation year t. We used the natural logarithm since the distribution is highly skewed. We also included standard-specific patent measures: *firm patent–TDMA* and *firm patent–CDMA*, counting a firm's patents in TDMA- and CDMA-related patent classes.

An indicator set of a firm's primary activity controls for industry fixed effects : (a) equipment manufacturing (SIC 3661, 3663, 3669, 3672, 3674, 3679, 3571, 3575 and 3577), (2) phone services (SIC 4812 and 4113), (3) maker of complimentary products/services mainly purchased by end users (consumers) (consumer electronics SIC 3651, prepackaged software SIC 7372, and information retrieval services SIC

7375) and (4) maker of complementary products purchased by phone companies (computer integrated systems design, SIC 7373; computer facilities management services, SIC 7376; or telecom product services, SIC 4899).

We controlled for *Common Geographical Region* using a dummy variable. Both homophily theory and agglomeration economics suggest that two co-located organizations are more likely to form a tie. We coded this variable 1 if the candidate firm's headquarter is located in the same geographical region as the sponsor (Qualcomm: North American; Ericsson: European), otherwise 0.

We controlled for whether a firm previously had an alliance with the sponsor. *Prior Tie* was set to 1 if a candidate had already partnered with the sponsor, 0 otherwise. Familiarity foster trust and reduces uncertainty about how a partnership will unfold (Gulati, 1995; Li and Rowley, 2002).

Network-level controls. *Network Cohesion* was calculated as the number of alliance ties in a firm's ego network divided by number of possible ties. The ego network includes the firm's direct alliance ties and alliance ties among alliance partners. The denser a firm's ego network the more likely that the firm will form an alliance with others inside the ego network (Koka and Prescott, 2002).

The variable *Common Third Party* indicates whether a given sponsor-potential partner dyad shared partners from previous alliances within the previous three years (t-4 to t-1). Firms tied to a common partner is assumed to have access to reliable information about one other through the common partner and can also experience relational pressures to form a tie due to common interests or for competitive reasons (Gulati and Garguilo, 1999).

Isolate indicates whether a candidate partner stood entirely outside the alliance network with no alliances in the total 2G-alliance network (1: yes, 0: no).

We also control for two industry-level network variables. *Network Centralization* measures heterogeneity in firm network centrality. A higher score captures that an alliance network was centralized around fewer firms in a given year. The variable is a ratio varying between 0 (all firms have equal centrality scores) and 1 (one firm dominates the network) and is operationalized as the average difference between the centrality of the most central firm and that of all other firms (Freeman, 1977), or:

$$Centralization = \frac{\sum_{i=1}^{n}[C_{max} - C_i]}{n-1}$$

where C_{max} is the centrality measure of the most central firm and n is the number of firms in the network.

Network Density is the number of alliances formed divided by the number of possible alliances in our alliance network dataset. A denser network can alter alliance-seeking behaviors with rapid alliance formation more likely in a sparse network while a denser network is more inert (Dodds and Watts, 2007) as sponsors need fewer alliances in order to channel information when many parties already are connected.

Technology-level controls. Installed base is seen as a key a determinant of a technology's ability to attract new adherents (Birke, 2009). We used the cumulative number of US phone companies that adopted each standard to capture the installed base of the standard, labeling these variables *TDMA_adoption* and *CDMA_adoption.*

We expect technoogical uncertainty to impact partner choices and use two measures: standards-specific patents and regulatory factors. First, the standards-specific patent count signals both technological competence in and credible commitment to the standard. We expect higher patent count to lower uncertainty (Singh, 2008) as it signals R&D investment in the standard. We use the count of patents in TDMA-and CDMA-related patent classes, *TDMA_patents* and *CDMA_patents*. Second, as no product could be sold until there was a formal standard approved and issued by the standards association TIA, we also included the time since a standard was approved, expecting uncertainty to decrease over time. Since the two standards had different approval dates, *TIAclock_TDMA* is the difference between the current year and year 1989 in which TIA endorsed the TDMA standard and *TIAclock_CDMA* as the difference between the current year and year 1993 in which TIA approved CDMA as a digital standard.

RESULTS

Table 1A and 1B reports the descriptive statistics and correlations for the Qualcomm and Ericsson models. We found that joint ventures comprised about 30% of Ericsson's alliances (10 out of 33) and 14% of Qualcomm's alliances (15 of 104). Qualcomm formed 29 alliances for R&D alliances (28% of its total) and

Ericsson formed 17 (52% of its total). Qualcomm also formed dramatically more manufacturing and marketing alliances (60, or 58% compared to 6, or 18%, of a sponsor's total ties, for Ericsson).

- Insert Table 1A & 1B about here -

Estimation Strategy

To test our hypotheses we analyze each sponsor's alliance network separately using piecewise exponential hazard models. This avoid biases created by right censoring and we need no a-priori assumptions regarding the duration dependence since the model's flexibility allows different diffusion rates, which fits with the empirical context. TDMA (Ericsson) was developed earlier than CDMA (Qualcomm) and we expect adoption likelihoods for the two standards to vary over time (Blossfeld and Rohwer, 1995).

We specify two periods signifying the pre and post market entry for the two technologies. In the Qualcomm models the two periods are (1989-1996) and (1997-2000), the break coinciding with the start of South Korean commercialization in 1996 and Bell Atlantics launch of the first US CDMA service (Bekkers, 2001). For the Ericsson models two other periods were specified (1989-1992) and (1993-2000), with the break in hazard rates indicating that the first TDMA system began US operations in 1992 (Singh, 2008).

We kept firm observations in the dataset until an event (an alliance between a sponsor and a candidate firm) occurred after which we dropped the candidate firm. This approach reduces the risk of endogeneity (e.g. the conditions for a second alliances is impacted by the first) and provides a more conservative test of our theory). We updated the time lagged and time-varying independent variables each year, estimating the coefficients using maximum likelihood methods. We have repeated observations for most candidate firms and used the "cluster" option in Stata for robust standard errors.

Comparing network coefficients (H1-H3) across the two models, we find systematic differences in sponsor strategies (see Table 2A and 2B). To establish the robustness, we estimated a rare events model to account for potential biases due to the sparseness of the networks, and successfully replicated the results. To probe further, we explored time effects of uncertainty on network strategies by adding interaction terms between the theoretical network variables and the uncertainty variables. Finally we focus on alliance candidate choices by running a multinomial logit with a dependent variable allowing each candidate to join the Ericsson, the Qualcomm, or no alliance network (see Appendix B).

- Insert Table 2A and Table 2B about here -

Qualcomm Model

Table 2A presents the hazard model results for Qualcomm's alliance partner network. Hypothesis 2 predicts that a technology sponsor offering an unproven technology, Qualcomm, would form alliances consistent with a wide bridge diffusion strategy. The hypothesis is supported as the *wide-bridge* coefficient is significant and positive (Model 2-6: 1.15<β, $p < 0.05$). We also find a weak negative effect for the *peer-to-peer* variable (Model 3-6: -1.38< β, $p < 0.1$). Hence, this suggests that Qualcomm tended to form dense ties around its partners, and was less likely to form a tie in a clique where it lacked partners. In each case, Qualcomm activates several firms in the potential adopter network that are connected by locally dense ties, where wide bridges can form. The positive effect of *centrality* (28.94<β, $p<.01$) suggests that Qualcomm sought to partner with central firms in the candidate partner networks, supporting H3.

Controls for CDMA patent stock, industry affiliation, isolate status, national differences, network centrality, and network density are consistently significant across the models (p-value ranges from < 0.05 to <0.001). We entered the uncertainty variables separately into the models since they are highly collinear. Two indicators for industry affiliations (if a firm is in manufacturing or providing complementary products) have positive and significant effects, suggesting that firms in these categories were key allies for Qualcomm during the observation period. This does not make firms in other categories unattractive as partners, but the results indicate that Qualcomm firstly tried to partner with complementary manufacturers to signal to others that their standard had backers. A positive and significant coefficient for the CDMA patent stock variable is consistent with the idea that Qualcomm was more likely to partner with firms that could contribute to its technology development. A negative and significant effect of market/regulation uncertainty suggests that Qualcomm tended to rely on alliances for diffusing its standard in the face of high market and regulatory uncertainties. As these uncertainties are reduced (e.g. more carrier adopters or TIA endorsement), their alliance likelihood decreases, meaning that Qualcomm formed fewer alliances after the uncertainties declined.

Ericsson Model

Table 2B presents the hazard model results for the Ericsson alliance partner network. Hypothesis 1 states that a technology sponsor with a proven technology would form alliances consistent with a peer-to-peer diffusion strategy, which is supported in Models 2-7, where the effect of *peer-to-peer* is positive and significant ($2.47<\beta<$, $p < 0.05$).

Ericsson entered fewer alliances than Qualcomm, which is also consistent with the peer-to-peer strategy where only a few key connections are needed to accelerate diffusion (Dodds and Watts, 2007). Industry history and interviews lend additional support to our finding: Ericsson clearly questions the value of alliances (Färjh & Wahlberg, 2014). An executive active in Ericsson during the 2G standards setting period in the 1980s, now Head of Standardization Strategy in ICT stated that the firm views collaboration as useful prior and during to the standards setting. Once a standard is established former standards partners are competitors and the fight is on.

Qualcomm's view of alliances was the opposite as they say in its 1999 annual report:

> "The Company has an ongoing commitment to the evolution and expansion of its technologies and products through strategic partnerships and alliances. These partnerships and alliances are designed to ensure product leadership and competitive advantage in the marketplace".

Comparing control variable effects for both sponsors, we found two interesting difference. First, Ericsson pursued neither technologically capable potential partners (firms with many TDMA patents) nor central parties in the network for alliances (Table 2B), while Qualcomm did (Table 2A). Second, Ericsson's alliance tendency was not influenced by uncertainty reduction over time, while Qualcomm's partnership pattern was greatly impacted by this factors (Table 2A). A similar effect for both sponsors is that they formed many alliances with isolates. When looking at the industry background of the isolates we find that many are entrants into telecom, with Ericsson isolate partners coming from the software industry, and Qualcomm isolate partners being equipment makers.

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Figure 1. An exemplar case of wide bridge strategy influencing potential adopters

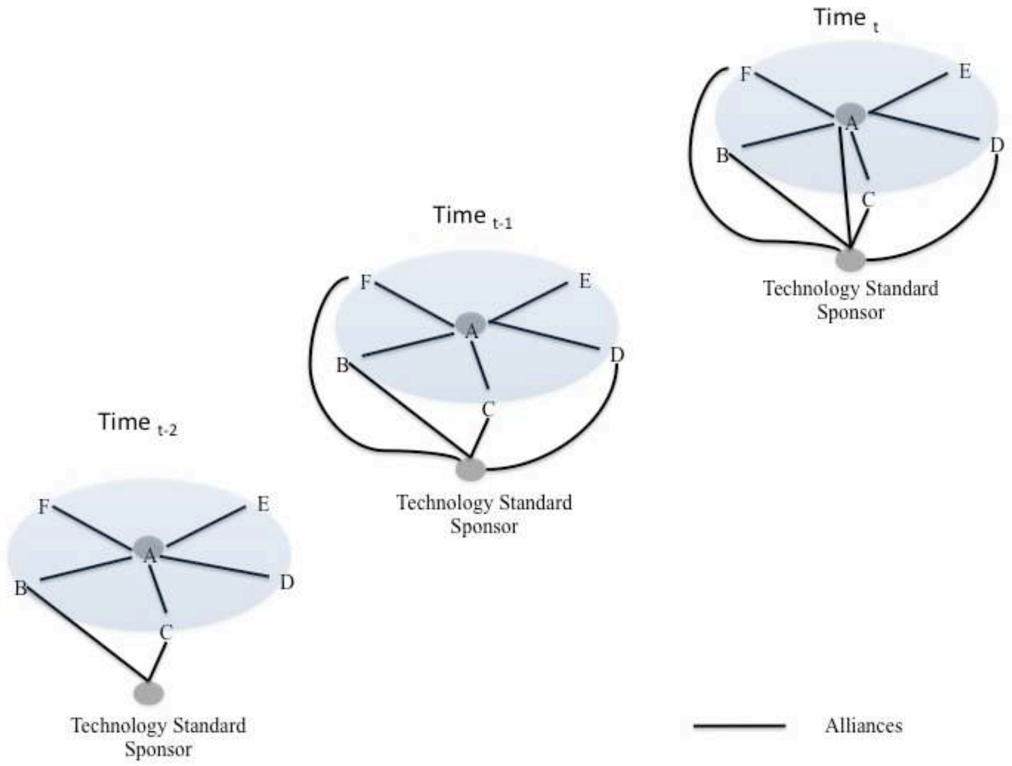


Figure 2. An exemplar case of peer-to-peer strategy influencing potential adopters

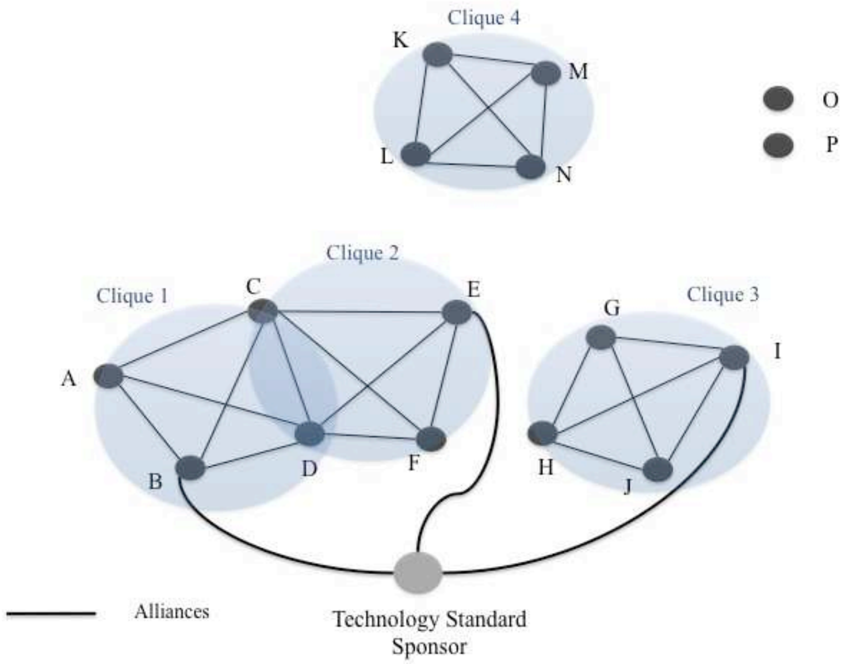


Table 1A. Correlation Table: Qualcomm model

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Public	1.00																		
2	Patent stock	0.05	1.00																	
3	Patent - CDMA	-0.02	0.23	1.00																
4	Equipment manufacturer	0.26	-0.07	-0.02	1.00															
5	Phone	-0.07	-0.03	0.00	-0.52	1.00														
6	Complementary makers for end user	-0.07	0.02	0.01	-0.33	-0.06	1.00													
7	Common geographic region	0.04	-0.17	-0.09	0.21	-0.09	-0.07	1.00												
8	Prior tie_Q	-0.32	0.00	0.00	-0.38	0.15	0.16	-0.19	1.00											
9	Isolate_Q	0.00	0.08	0.02	-0.20	0.13	0.08	-0.13	0.16	1.00										
10	Network cohesion	-0.39	0.00	0.02	-0.56	0.29	0.18	-0.25	0.58	0.10	1.00									
11	Common 3rd party	-0.01	0.19	0.27	-0.24	0.21	0.11	-0.19	0.11	0.17	0.18	1.00								
12	Network centralization	-0.02	-0.01	-0.06	-0.05	0.04	0.01	-0.01	-0.06	-0.01	0.07	0.05	1.00							
13	Network density	0.05	0.00	-0.07	0.09	-0.07	-0.04	0.01	0.37	-0.04	-0.14	-0.06	-0.16	1.00						
14	CDMA_adoption	-0.03	0.01	0.10	-0.03	0.04	0.03	0.00	-0.31	0.05	0.06	0.05	-0.33	-0.78	1.00					
15	TIAclock_CDMA	-0.02	0.02	0.11	0.00	0.02	0.02	0.01	-0.26	0.03	0.02	0.02	-0.53	-0.61	0.92	1.00				
16	CDMA_patents	-0.01	0.03	0.10	0.02	0.00	0.01	0.03	-0.19	0.01	0.00	-0.01	-0.46	-0.40	0.67	0.88	1.00			
17	Wide-bridge_Q	-0.07	0.07	0.05	-0.26	0.16	0.14	-0.17	0.21	0.09	0.34	0.51	0.01	-0.02	0.03	0.04	0.05	1.00		
18	Peer-to-peer_Q	-0.10	0.02	-0.01	-0.22	0.11	0.02	-0.14	0.13	-0.03	0.23	-0.06	0.03	-0.04	-0.02	-0.04	-0.06	-0.07	1.00	
19	Centrality	-0.14	0.30	0.35	-0.27	0.17	0.04	-0.12	0.14	0.04	0.15	0.61	0.04	0.03	-0.05	-0.06	-0.05	0.14	0.16	1
	Mean	0.87	0.52	2.98	0.75	0.08	0.04	0.80	0.56	0.04	0.40	0.27	0.34	0.02	427.1	2.00	2240	0.07	0.05	0.01
	S.d.	0.34	1.42	23.87	0.43	0.28	0.19	0.40	0.50	0.21	0.48	0.94	0.04	0.01	219.7	2.11	3451	0.22	0.22	0.02

N = 3293. Correlations above 0.005 are significant at $p<0.05$

Table 1B. Correlation Table: Ericsson model

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Public	1.00																		
2	Patent stock	0.05	1.00																	
3	Patent - TDMA	-0.02	0.22	1.00																
4	Equipment manufacturer	0.26	-0.07	0.01	1.00															
5	Phone	-0.07	-0.03	-0.02	-0.52	1.00														
6	Complementary makers for end user	-0.07	0.02	-0.02	-0.33	-0.06	1.00													
7	Common geographic region	0.01	0.17	0.17	-0.19	0.09	0.09	1.00												
8	Prior tie_E	-0.34	-0.02	-0.01	-0.38	0.15	0.14	0.12	1.00											
9	Isolate_E	-0.08	0.09	0.17	-0.13	0.08	0.03	0.10	0.06	1.00										
10	Network cohesion	-0.39	0.00	-0.02	-0.56	0.29	0.18	0.24	0.55	0.04	1.00									
11	Common 3rd party	-0.09	0.16	0.29	-0.31	0.25	0.09	0.23	0.22	0.22	0.30	1.00								
12	Network centralization	-0.02	-0.01	-0.03	-0.05	0.04	0.01	0.03	-0.05	0.00	0.07	0.04	1.00							
13	Network density	0.05	0.00	-0.04	0.09	-0.07	-0.04	0.01	0.39	0.00	-0.14	-0.06	-0.16	1.00						
14	TDMA_adoption	-0.04	0.01	0.06	-0.05	0.05	0.03	-0.03	-0.36	0.00	0.08	0.04	-0.35	-0.82	1.00					
15	TIAclock_TDMA	-0.04	0.01	0.06	-0.04	0.04	0.03	-0.04	-0.35	0.00	0.07	0.05	-0.36	-0.80	0.98	1.00				
16	TDMA patents	-0.03	0.02	0.06	-0.02	0.03	0.03	-0.04	-0.32	0.00	0.05	0.05	-0.43	-0.73	0.95	0.99	1.00			
17	Wide-bridge_E	-0.17	0.01	0.02	-0.33	0.15	0.15	0.15	0.29	0.02	0.42	0.64	0.06	-0.06	0.02	0.01	0.00	1.00		
18	Peer-to-peer_E	-0.06	0.03	0.00	-0.24	0.16	0.04	0.07	0.14	-0.02	0.24	-0.08	0.03	-0.05	0.02	0.00	-0.02	-0.10	1.00	
19	Centrality	-0.14	0.30	0.36	-0.27	0.17	0.04	0.15	0.15	0.42	0.15	0.39	0.04	0.03	-0.04	-0.05	-0.05	0.04	0.21	1
	Mean	0.87	0.52	0.83	0.75	0.08	0.04	0.13	0.54	0.02	0.40	0.21	0.34	0.02	506.1	4.39	1234	0.11	0.06	0.01
	S.d.	0.34	1.42	8.41	0.43	0.28	0.19	0.34	0.50	0.13	0.48	0.56	0.04	0.01	252.8	2.83	674	0.28	0.23	0.02

N = 3293. Correlations above 0.005 are significant at $p<0.05$

Table 2A. Results of Regression Analyses Predicting Sponsor's Partner Strategy: Qualcomm

	Model 1			Model 2			Model 3			Model 4			Model 5			Model 6		
	coef.	s.d.		coef.	s.d.		coef.	s.d.		coef.	s.d.		coef.	s.d.		coef.	s.d.	
1990-1996	-1.56	2.13		-0.81	2.11		-0.22	2.07		3.90	3.09		4.11	3.07		0.30	2.25	
1997-2000	-2.68	1.82		-2.13	1.80		-1.68	1.76		2.39	2.79		3.09	2.85		-0.44	2.05	
Public	0.65	0.32	*	0.64	0.32	*	0.64	0.32	*	0.58	0.32	+	0.54	0.32	+	0.60	0.31	+
Patent stock	0.12	0.07		0.12	0.06	+	0.12	0.06	+	0.14	0.06	*	0.13	0.06	*	0.12	0.06	+
Patent - CDMA	0.02	0.00	***	0.02	0.00	***	0.02	0.00	***	0.02	0.00	**	0.02	0.01	***	0.02	0.01	**
Equipment manufacturer	0.49	0.29	+	0.50	0.28	+	0.43	0.28		0.57	0.28	*	0.58	0.28	*	0.48	0.27	+
Phone	0.28	0.34		0.31	0.34		0.21	0.35		0.19	0.35		0.17	0.35		0.24	0.35	
Complementary makers for end user	1.09	0.37	**	1.12	0.36	***	1.05	0.34	**	1.22	0.36	***	1.25	0.35	***	1.12	0.34	***
Common geographic region	-0.63	0.22	**	-0.63	0.22	**	-0.67	0.22	**	-0.70	0.22	***	-0.68	0.21	***	-0.64	0.22	**
Prior tie_Q	1.16	0.52	*	1.10	0.52	*	1.04	0.53	*	1.05	0.53	*	0.98	0.54	+	0.91	0.52	+
Isolate_Q	3.93	0.41	***	4.01	0.41	***	4.03	0.42	***	4.08	0.43	***	4.16	0.44	***	4.20	0.46	***
Network cohesion	0.40	0.41		0.28	0.43		0.42	0.44		0.44	0.44		0.54	0.45		0.64	0.48	
Common 3rd party	-0.07	0.15		-0.28	0.20		-0.37	0.22	+	-0.38	0.24		-0.37	0.23		-0.38	0.23	
Network centralization	-8.88	4.84	+	-10.48	4.82	*	-11.47	4.74	*	-18.02	6.20	**	-19.94	6.68	**	-12.56	5.14	*
Network density	-79.93	25.31	**	-91.25	25.08	***	-98.19	24.61	***	-164.47	42.37	***	-158.21	39.20	***	-104.02	27.09	***
CDMA_adoption										0.00	0.00	*						
TIAclock_CDMA													-0.33	0.13	*			
CDMA_patents																0.00	0.00	
Wide-bridge_Q				1.23	0.58	*	1.23	0.57	*	1.28	0.57	*	1.23	0.57	*	1.15	0.57	*
Peer-to-peer_Q							-1.32	0.80	+	-1.36	0.81	+	-1.38	0.81	+	-1.38	0.79	+
Centrality	28.94	7.66	***	34.04	7.69	***	39.39	8.46	***	39.06	8.59	***	39.17	8.55	***	39.29	8.55	***
Wald χ^2	-117.9		***	-111.1		***	-109.05		***	-107.51		***	-106.72		***	-107.25		***
Pseudo likelihood	932.15			918.24			901.06			882.47			885.35			923.11		

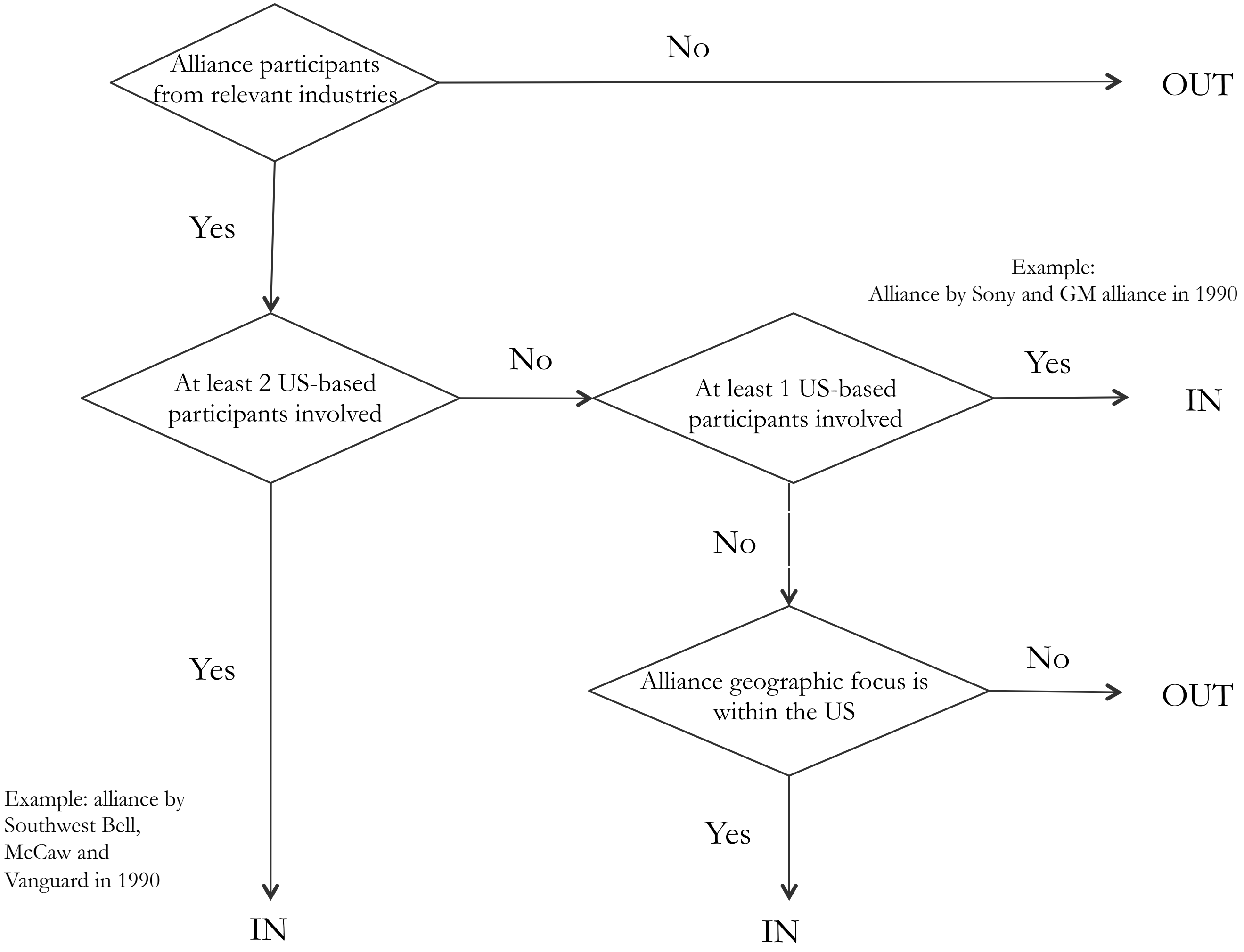
The analysis is based on 3036 firm-year observations (three-year alliance duration window) covering 723 firms and 77 events of Qualcomm's alliances. +p<0.10; *p<0.05; **p<0.01; ***p<0.001.

Table 2B. Results of Regression Analyses Predicting Sponsor's Partner Strategy: Ericsson

	Model 1			Model 2			Model 3			Model 4			Model 5			Model 6		
	coef.	s.d.		coef.	s.d.		coef.	s.d.		coef.	s.d.		coef.	s.d.		coef.	s.d.	
1990-1992	7.76	4.34	+	6.75	4.06	+	6.07	4.04		5.77	8.49		3.23	8.66		4.09	8.77	
1993-2000	3.90	3.32		3.09	3.07		2.51	3.11		2.18	8.12		-0.45	8.17		0.54	8.05	
Public	-0.54	0.56		-0.28	0.44		-0.18	0.45		-0.15	0.43		-0.22	0.43		-0.21	0.42	
Patent stock	0.20	0.13		0.10	0.15		0.14	0.16		0.15	0.16		0.13	0.16		0.13	0.16	
Patent - TDMA	0.01	0.01	+	0.01	0.01	+	0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01	
Equipment manufacturer	0.65	0.65		0.57	0.53		0.65	0.54		0.71	0.56		0.67	0.56		0.67	0.56	
Phone	0.60	0.93		0.40	0.92		0.42	0.96		0.51	0.98		0.45	0.95		0.44	0.94	
Complementary makers for end user	1.53	0.88	+	1.46	0.77	+	1.39	0.70	*	1.37	0.68	*	1.35	0.68	*	1.37	0.68	*
Common geographic region	0.36	0.74		0.18	0.72		0.12	0.67		0.16	0.66		0.17	0.69		0.16	0.68	
Prior tie_E	-0.81	0.82		-0.70	0.82		-0.69	0.79		-0.57	0.82		-0.69	0.79		-0.69	0.79	
Isolate_E	6.19	0.79	***	6.37	0.78	***	6.67	0.94	***	6.66	0.98	***	6.66	0.96	***	6.66	0.95	***
Network cohesion	-0.39	0.98		-0.74	1.10		-1.38	1.64		-1.39	1.67		-1.49	1.79		-1.47	1.83	
Common 3rd party	2.24	0.98	*	2.77	1.11	*	1.89	1.25		1.88	1.23		1.82	1.20		1.84	1.20	
Network centralization	-23.21	8.73	**	-22.43	8.65	**	-21.52	8.30	**	-21.62	12.15	+	-17.53	13.09		-18.54	13.57	
Network density	-234.2	68.06		-210.2	63.61		-211.90	61.31		-212.88	162.44		-161.66	147.42		-181.41	137.42	
TDMA_adoption										0.00	0.00							
TIAclock_TDMA													0.15	0.35				
TDMA patents																0.00	0.00	
Wide-bridge_E							2.11	1.96		2.15	2.00		2.26	2.17		2.22	2.19	
Peer-to-peer_E				2.47	1.09	*	2.59	1.17	*	2.63	1.21	*	2.67	1.27	*	2.65	1.29	*
Centrality	-16.52	18.63		-30.63	24.99		-0.62	24.96		0.87	25.83		2.02	26.53		1.29	26.63	
Wald χ^2	474.95		***	533.68		***	419.39		***	487.48		***	492.87		***	491.96		***
Pseudo likelihood	-30.03			-27.82			-27.03			-27.01			-26.92			-26.97		

The analysis is based on 3212 firm-year observations (three-year alliance duration window) covering 725 firms and 17 events of Ericsson's alliances.
+p<0.10; *p<0.05; **p<0.01; ***p<0.001.

APPENDIX A.
Establishing the Risk Set and Boundaries of the Potential Adopter Network



APPENDIX A (continued)
Establishing the Risk Set and Boundaries of the Potential Adopter Network

Category	SIC	Frequency	Percentage
Equipment manufacturing	3663	284	39.2%
Equipment manufacturing	3661	33	4.6%
Equipment manufacturing	3674	31	4.3%
Equipment manufacturing	3577	18	2.5%
Equipment manufacturing	3679	17	2.3%
Equipment manufacturing	3571	13	1.8%
Equipment manufacturing	3669	12	1.7%
Equipment manufacturing	3575	4	0.6%
Phone operator	4812	47	6.5%
Phone operator	4813	45	6.2%
Maker of complementary products_end user	7372	33	4.6%
Maker of complementary products_end user	3651	12	1.7%
Maker of complementary products_end user	7375	5	0.7%
Maker of complementary products_phone	4899	16	2.2%
Maker of complementary products_phone	7373	9	1.2%
Maker of complementary products_phone	7376	2	0.3%
Others	5045, 7371, 3825, 5065, 3812, 4832, 4841, 3823, 3312, 3714, 3721, 3873	143	19.8%
Total		724	100.0%

APPENDIX B[1].
Results of Multinomial Logit Analyses Predicting Candidates' Partnership Choice among Ericsson, Qualcomm, and no partnership
('no partnership' is the baseline model for interpreting the coefficients)

	Model 1				Model 2				Model 3				Model 4			
	Ericsson		Qualcomm		Ericsson		Qualcomm		Ericsson		Qualcomm		Ericsson		Qualcomm	
Public	0.89		1.75	**	1.26	*	1.70	**	1.22		2.15	***	1.18		1.92	**
Patent stock	0.26	+	0.17	*	0.15		0.17	*	0.31	***	0.22	*	0.28	**	0.22	**
Firm patent – CDMA	0.05	**	0.06	**	0.04	*	0.06	**	0.08	***	0.08	***	0.07	***	0.08	***
Firm patent – TDMA	-0.05	**	-0.06	**	-0.04	*	-0.06	**	-0.07	***	-0.07	***	-0.06	***	-0.07	***
Equipment	0.23		0.88		0.20		0.82		0.50		1.29	+	0.41		1.26	+
Phone	1.18		0.59		1.83		0.47		1.33		0.74	+	1.59		0.66	
Complementary makers for end user	1.41		1.50	**	1.54		1.46	**	1.54		1.64	**	1.46		1.74	**
Common geographic region_Q[2]	**13.15**	***	**-0.18**		**14.47**	***	**-0.14**		**14.07**	***	**-0.82**		**13.42**	***	**-0.29**	
Common geographic region_E	**14.27**	***	**1.32**		**15.75**	***	**1.34**		**15.09**	***	**0.47**		**14.61**	***	**1.11**	
Prior tie	-0.96		1.78		-1.37		1.84		-1.69		0.45		-1.47		0.76	
Isolate	4.81	**	3.78	**	4.94	**	3.73	**	5.18	***	3.75	**	5.19	**	3.86	**
Network cohesion	**-1.63**		**-1.71**	***	**-1.95**		**-1.75**	***	**-2.04**		**-2.69**	***	**-1.96**		**-2.59**	***
Common 3rd party_Q	0.65		0.21		0.52		0.18		0.64		0.62	**	0.52		0.40	+
Common 3rd party_E	-0.16		0.49		0.05		0.50		-0.22		0.21		-0.15		0.35	*
Network centralization (industry)	19.94		9.14		35.97		9.39		2.67		-30.38	***	0.25		-48.16	***
Network density (industry)	**172.98**		**110.42**	**	**-266.00**		**106.78**	*	**103.45**		**-77.25**	*	**64.54**		**-226.17**	***
Market catch-up: Ratio of (CDMA adoption /TDMA adoption)					**5.12**	*	**0.02**									
Technology catch-up: Ratio of (CDMA patents/TDMA patents)									**-0.01**		**-0.02**	***				
Competition clock: TIAclock_CDMA													**-0.47**		**-1.41**	***
Pseudo likelihood	-163.24				-158.50				-137.11				-139.24			
Pseudo R^2	0.44				0.46				0.53				0.52			

N=724 firm observations; +p<0.10; *p<0.05; **p<0.01; ***p<0.001.

(1) Models with the inclusion of explanatory variables (wide-bridge and peer-to-peer) are not in this table, but available upon request. Candidate firms are unlikely to choose a sponsor based on the sponsor's network strategy, as this is likely invisible to them. We focus on what firm attributes make a sponsor more attractive to potential partners. For each firm that allied with a sponsor, we used only one observation at the time of their alliance formation with the sponsor. For firms that had no alliances with them, we used observations at the end of the firm sample time period. There were only three firms that allied with both sponsors during our time period. We classified these firms according to which sponsor they partnered with first.

(2) The variables in bold font are the ones where the significance/direction of the influence of firm attribute variables on the likelihood of partnership with sponsors differs between Qualcomm and Ericsson.