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Committee Composition and Networking in Standard Setting: The Case of Wireless Telecommunications

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We examine factors behind firms' decisions to contribute to open standard setting. Our study highlights a novel explanation: firms seek to improve their positions in an interfirm cooperation network. In the wireless telecommunications standard-setting organization we study, firms develop new technical specifications in small committees. Our panel data analyses demonstrate that interorganizational network connections influence firms' decisions to support committees. Additionally, firms are more likely to support committees when they are technologically distant from the firm that initiated the committee. We argue that standard setting presents opportunities for information exchange and for accessing complementary R&D assets through the cooperation network.

1. Introduction

Technical standards influence the terms of competition in network-technological industries such as communication and information technologies. As noted by Farrell et al. (1998), the nature of "component competition" within a standard drastically differs from that of "systems competition" between standards. In many network industries, there is a strong cooperative element to standardization and firms make substantial financial investments in cooperative standard-setting organizations.[1] Nevertheless, to date, management and economic research have contributed relatively little to our understanding of the process of cooperative standard setting. We study the standard-setting process in a major wireless telecommunications standards development organization, Third Generation Partnership Project (3GPP) through the lens of social (interorganizational) network formation by strategically motivated firms.

The 3GPP standard specifications are created in temporary committees. Participation in these "work-item" committees entails substantial investment of human and

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1. See for example, Greenstein and Stango (2007, pp. 1–15).

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financial resources. We analyze the repeated decisions of 44 member firms to support (join and contribute to) these committees. Our premise is that firms' participation in the cooperative standard-setting organization, and particularly their investment in work-item committee activities, reflects their desire to maximize private payoffs. Previous empirical studies of cooperative standard-setting organizations have highlighted the roles of market power and intellectual property (IP) in determining firms' ability to influence standardization processes (Weiss and Sirbu, 1990; Bekkers et al., 2002; Simcoe, 2007, 2012; Rysman and Simcoe, 2008). However, firms with essential patents related to the standard are a small minority in 3GPP. We argue that in addition to the royalty motivation there are other reasons for firms to participate in formal standard setting. Standard setting presents opportunities for early information exchange, and through collaboration firms gain access to other firms' complementary R&D assets.

Our goal is to better understand what drives firms' active participation in the cooperative standard-setting process. We focus on two aspects of information exchange: social network connections and technological complementarities among firms. We investigate how firms' decisions to support work-item committees are influenced by social network considerations, and whether firms participate in work-item committees primarily to compete with and monitor rival firms, or to learn and benefit from the expertise of other firms that have complementary capabilities.

Firms who are in the same work-item committee jointly develop a technical specification for a new feature. Such collaboration creates opportunities for information exchange. These can naturally be modeled with a social network. In our empirical context, the social network is created by firms' participation in work-item committees. Two firms that support the same committee are defined as directly connected. This social network evolves over time as more work-item projects are started. In the economic literature on social networks (see e.g., Jackson and Wolinsky, 1996), it is assumed that forming direct connections entails both costs and benefits, but firms benefit from indirect connections without incurring costs above and beyond the costs of direct connections. Hence, being directly connected to others who are well connected is beneficial. It enables access to information through indirectly linked peers. Benefits from connections to other firms can arise from information exchange and integration of knowledge from the parties in a work-item project. Connections to potential clients may also enable advertising of a firm's expertise or technologies.

Following a large literature on alliance management, we argue that firms learn to cooperate with specific partners, and therefore, the costs of cooperation are higher when firms work with new partners—form new direct connections (see Heide and Miner, 1992; Ring and Van De Ven, 1992; Gulati, 1995, among others). Firms' representatives build trust and learn to cooperate with one another and become a more effective team as they repeat projects with the same partners. Hence, the bulk of the cost of social network activity is associated with the formation of new direct ties.

We hypothesize that firms prefer their existing direct connections over new connections, because the latter present an additional cost of connection formation. Nevertheless, firms benefit from indirect ties to other firms through their directly connected committee partners. Therefore, whenever they have an opportunity to connect with a well-connected new partner, they may forego the cost of a new direct connection in order to be able to benefit from the associated indirect connections.

We will assess the two competing views on standardization regarding whether firms tend to form committees based on technological similarity or complementarity. Firms may participate in work-item committees primarily to compete with and monitor rival firms, or to learn from and utilize the expertise of other firms that have complementary capabilities. If the former argument is true, we would expect to find that firms are more likely to support committees where they are similar to others in terms of R&D portfolios, and that committees are homogeneous in terms of industry representation. If the latter argument is true, we would expect firms to support committees where their technological assets are different from the focal firm, and committees that are diverse in terms of industry representation.

We collected a unique data set of 64 consecutive work-item committees and firms that supported them in 3GPP's Radio Access Network Technical Specification Group for the period of 2000–2003. We also generated a set of network variables from the evolving social network induced by work-item committee participation observed in our data. Using firm fixed-effects and instrumental-variable panel-data analyses and controlling for the nature of the committee, we find statistical support for our hypotheses regarding the roles of technological complementarities and social network connections in driving participation in work-item projects.

Our study contributes to the growing literature on cooperative standard setting with two novel empirical findings. First, we show that firms strategically position themselves in the evolving interfirm cooperation network. Our results support the notion of preferential attachment to highly connected peers: by examining the evolution of both direct and indirect connections, we find that firms generally prefer to work with familiar partners and shy away from new direct connections, but they seek to form new indirect social network connections. Second, we find that firms are more likely to participate in committees when their technological assets are different from those provided by the original source of the work item (the technical feature). This result suggests that collaboration in work-item committees is primarily based on technological complementarities. Taken together, our results can be interpreted to mean that information exchange—learning, influencing, and advertising—is a strategically important aspect of cooperative standard-setting. Our framework thus highlights incentives to contribute to open standard setting beyond the opportunities to insert IP in the standard in the expectation of royalty revenue.

This paper is organized as follows: Section 2 reviews related literature; Section 3 describes the committee-based standard-setting processes in the Third Generation Partnership Project; Section 4 describes the data; Section 5 describes the regression analyses; and Section 6 offers concluding remarks.

2. Related Literature

The economic literature on standard setting has primarily focused on market-based standards battles (e.g., Katz and Shapiro, 1985; Katz and Shapiro, 1994). Models of cooperative standard setting include Farrell and Saloner (1988), Simcoe (2007, 2012), Farrell and Simcoe (2012) and Lerner and Tirole (2006). The first four of these papers model the creation of committee-based standards as a war of attrition and examine the efficiency of this form of standardization. Simcoe (2007, 2012) and Farrell and Simcoe (2012) focus particularly on the role of intellectual property rights (IPRs). Lerner and Tirole (2006), on the other hand, examine the choice of standardization forum through a model of forum shopping. None of these studies have recognized the nature of standard setting as a network of cooperation and communication, which is the viewpoint taken in our research.

A network-analytical approach has been taken by a few earlier empirical studies of standard setting. Leiponen (2008) found that firms' ability to influence formal standardization depends on their connections to peers in other technical industry consortia, and Delcamp and Leiponen (forthcoming) examine the effects of connections in other technical consortia on essential patent cross-citations. This suggests that firms participating in standardization operate in a network of influence and information exchange. In a related study, Rosenkopf and Tushman (1998) described how the nature of network evolution depends on the level of technological uncertainty. However, these studies examined firms' decisions to join multiple cooperative technical organizations (industry associations and consortia), although our focus is on the evolution of the committee network within one single standard-setting organization. Furthermore, our study more explicitly models firms' decisions to support committees that result in network evolution. Our paper also relates to the work of Rosenkopf and Padula (2008) who study network evolution in the mobile communications industry. They examine aspects of network change including the creation of shortcuts (links between weakly connected clusters) and entry of new firms into an existing network. They suggest that incumbent firms occasionally seek to form alliances with less familiar firms to access more unique knowledge.

More recently, Fershtman and Gandal (2011) empirically study a network of open-source software projects and developers. Our work is related to theirs in that we too examine an affiliation network (or a two-mode network) and account for direct and indirect spillovers. In their paper, however, the network is static, and they study how the network architecture affects project success. In contrast, the network evolves in our paper as firms choose to support work-item committees, and we focus on the decisions to support committees.

Informal discussions with practitioners and the observation that many firms without essential IP invest in work-item participation suggest that firms want to contribute to formal standardization even without the potential of royalty revenue. Non-IP-related benefits from standardization have been discussed by Waguespack and Fleming (2009) who find that startup companies receive financial benefits (greater likelihood of initial public offering or acquisition) simply from attending standard-setting meetings and, conditional on high attendance, from leadership positions in standardization working groups. Waguespack and Fleming suggest that advertising, obtaining information, developing trust with external sources of information, and influencing standards without large resource investment are driving these benefits.

Our hypothesis that firms enjoy information benefits from connections to peers is aligned with an extensive sociological literature on social networks (e.g., Powell and Smith-Doerr, 1996; Gulati, 1999; Dyer and Nobeoka, 2000; Owen-Smith and Powell, 2004). We suggest that firms derive net benefits from collaborating with well-connected firms. In the small-world network literature, this phenomenon is a well-documented driver of network evolution termed "preferential attachment" (e.g., Barabasi and Albert, 1999; Amaral et al., 2000).

3. Third Generation Partnership Project

Our study assesses firms' decisions to contribute to cooperative standard setting through committee activities in one formal standard-setting organization, 3GPP. The notion of third-generation wireless telecommunications (3G) refers to the shift from digital voice communication (2G) to the era of "mobile internet" or "broad-band wireless," which expands the range of mobile communication services from transmission of voice to various kinds of data, including pictures and multimedia. These new services require substantially greater data transfer capabilities than does pure voice communication.

3GPP is the international standards development organization for one of the 3G standards, Universal Mobile Telecommunications System (UMTS). 3GPP evolved from the Special Mobile Group that operated under the European Telecommunications Standards Institute (ETSI) and that was responsible for the development of the previous Global System for Mobile (GSM) communication standards. Created in 1998, 3GPP is not a legal entity but a collaborative alliance among standardization organizations from three continents (North America, Europe, and Asia). Recognition of the need for worldwide standards for the next-generation cellular telephone systems implied that standardization activities be organized through a truly global organization. In 2000, there were 338 individual members in 3GPP ranging from telecommunication operators and equipment suppliers to various kinds of technical consultancies and R&D service firms. Individual members were able to participate in technical specification groups by attending meetings, contributing to specification development, and acting as chairpersons.

The development of technical specifications proceeded formally through work items. Work items are new technical features that are proposed by individual members. The firm that proposed the work item was referred to as the "source" of the work item. Each work item was proposed in a meeting where other firms chose whether to "support" the work item. Supporting (joining) a work-item committee implied that the firm took shared responsibility of drafting the technical specification with the other supporters of the work item. Work-item committees lasted around 13 months on average, and they involved substantial R&D work to figure out the details and draft the specification. Between 2000 and 2003, 363 work items were proposed and started in 3GPP technical specification groups, and 64 of these were in the Radio Access Network group studied here. Of the over 300 firms that were 3GPP members in 2000, only 62 firms participated in any work-item committees in all technical specification groups, and 51 of these organizations supported work items in the Radio Access Network group.[2] Moreover, such participation is highly concentrated within a few industry leaders.

These committee participation numbers are aligned with the view presented by Schmidt and Werle (1998) that many members in standards development organizations participate to learn about upcoming technologies and to align their innovation activities with the industry rather than to actively promote a standardization agenda involving the adoption of their preferred technical solutions. On the other hand, those members who invest resources in specification development are likely to be interested in specific technological outcomes that are associated with private benefits (Branscomb and Kahin, 1995).

Individual members of 3GPP are bound by the IPRs policies of their regional standardization bodies. In most cases this implies agreeing to license patents related to essential technologies under "fair, reasonable, and nondiscriminatory" (FRAND) terms. In reality, even if standards negotiations are open and nondiscriminatory, firms with the strongest patent portfolios and other technological assets may be the most influential.

2. Although 51 different organizations joined work item committees in the Radio Access Network group, supplementary data are only available for 44 of them. These 44 firms are included in the empirical analyses that follow.

Thus the opportunities to influence standards negotiations may indeed motivate and direct technology development and patenting activities (see Gandal et al., 2004). As a result, IP is one of the key elements in standards negotiations.

3GPP members are expected to declare a patent as "essential" when the underlying technology is necessary for the implementation of a new specification under development in standard-setting committees. The European Telecommunications Standards Institute keeps track of 3GPP-related IP. In 2005, their database contained 837 declarations of essential IPRs related to the third-generation wireless telecommunication network and including patents registered in the United States. However, these declarations originated from just 18 firms. Major communication technology firms such as Motorola, Ericsson, InterDigital, Qualcomm, Nokia, and Siemens were the dominant companies, each with dozens or even hundreds of declarations of IPRs initially registered with the United States Patent and Trademark Office. The small number of firms with any essential patent declarations suggests that participation in wireless telecom standard-setting committees is driven by other factors for the great majority of firms.

4. The Data

For our analysis we collected data on firms' participation in work-item committees in the 3GPP Radio Access Network group from meeting documents which are available online. We combined these data with information on firm size, IP holdings, industry affiliations, and activities in other technical consortia collected from sources such as company and consortium web sites and various databases including Hoover's, Micropatent, and the ETSI IPR database. Because 3GPP only started operations in 2000, we can track the origins and the evolution of this network of cooperative committees. Among several technical specification groups within 3GPP, we focus on the evolution of work-item cooperation networks within one single technical specification group, radio access networks (RAN), which was a central technical field within the whole UMTS system. This group is where the highly contested air interface and protocol specifications were negotiated and developed.

Specification development work in 3GPP was carried out continuously through email communication, but decisions and group discussions took place in face to face meetings three or four times a year. There was a great deal of stability in the meeting attendance patterns and teams for most companies. Based on information about the meeting representatives of each company, the same individuals tended to attend meetings repeatedly and consistently, independent of where the meeting was held. This is probably because being an effective standard-setting professional requires specific skills that take some time to learn, for which reason it makes sense to concentrate the standardization activities to a stable group of skilled engineers.

Our data follow specification development through 64 work items discussed in 14 meetings over a period of four years (2000–2003).[3] On average, 4.4 work items are proposed in each meeting. We observe all work-item committees—temporary committees that develop technical feature specifications for the standard—that are formed in

3. To make sure that the results are not driven by one outlying large work item, we exclude from the analysis a work item that was supported by 18 firms. We also exclude from estimation one work item committee that appears to have three supporters, because work items should have at least four. All other work items are supported by 4–10 firms. The median number of supporters is 5. Results remain unchanged if we include these work items. We accounted for these work items in the definition of the network variables.

these meetings. However, we cannot observe committees that failed to form, even though they may have been proposed by an attending firm representative. For each work item we observe the firms that proposed it that were called "sources," and the firms that joined it called "supporters." We assume that each committee constitutes a Nash equilibrium: fixing the behavior of all others, every supporter weakly preferred to support the work item, and every nonsupporter weakly preferred not to support it.

Each work-item proposal presented an opportunity for firms to decide whether to join ("support") the committee, and thus, potentially change their network positions. We assume that firms' collaborations in the organization induce a social network: a pair of firms is directly connected (or linked) if there is a work-item committee that they both supported. Work items were formed sequentially. Every time a new work-item committee was formed, the social network changed. For $t = 0$, before the first work item was formed, we have an empty network. For all $t \geq 1$, the direct connections firm i has at time t is the number of firms that had collaborated with firm i in one or more of the work items $1, 2, \ldots, t$. We also count indirect connections of different path lengths. The number of indirect connections of path length two is the number of firms that are not directly connected to firm i at time t, but that are directly connected to one of firm i's direct connections at time t. Similarly, we define indirect connections of path length three.[4]

In Figure 1, we illustrate the evolution of the network in the early stages. To better understand the concept of direct and indirect connections, consider the network after committee $t = 3$ had been formed, see panel 3. Note that Nortel had a direct connection to Ericsson (due to their joint support of committee $t = 3$). Nortel had an indirect connection of path length two to Nokia (since Ericsson was connected to Nokia in $t = 2$), and an indirect connection of path length three with InterDigital (that supported committee $t = 1$ with Nokia).

Our empirical network variables capture the potential changes in each firm's direct and indirect connections to peers that would be caused by supporting each work item. This allows us to empirically estimate how potential changes in the cooperation network influenced firms' activities in work-item committees. We denote the change in direct connections that firm i would experience by supporting the work-item committee t (fixing the decisions of all other firms) by $\Delta Connections1_{i,t}$. We denote the changes in indirect connections of length two and length three by $\Delta Connections2_{i,t}$ and $\Delta Connections3_{i,t}$, respectively. With reference to figure 1, the first committee to form had five supporters: InterDigital, Nokia, NTT DoCoMo, Siemens, and Vodafone. For Nokia, one of the firms that supported the committee $t = 1$ we have $\Delta Connections1_{Nokia,1} = 4$, which is the number of new direct connections it formed by supporting this committee. Motorola did not support this committee. If it had supported, it would have formed five new direct connections, as it would have connected directly with each of the supporters of the $t = 1$ committee. Therefore, for Motorola, in period $t = 1$, $\Delta Connections1_{Motorola,1} = 5$. For either firm, supporting the $t = 1$ committee does not change the number of indirect connections, $\Delta Connections2_{Nokia,1} = \Delta Connections2_{Motorola,1} = 0$.

The second committee in figure 1 has four firms: Ericsson, NEC, Nokia, and Siemens. For Nokia, in period $t = 2$, $\Delta Connections1_{Nokia,2} = 2$, because NEC and Siemens were new connections, but Ericsson was an existing connection from $t = 1$. For Nokia $\Delta Connections2_{Nokia,2} = 0$, because it did not form new indirect connections.

4. Our network also generates connections with a path length of four, but we exclude these from estimation models because they are never significant.

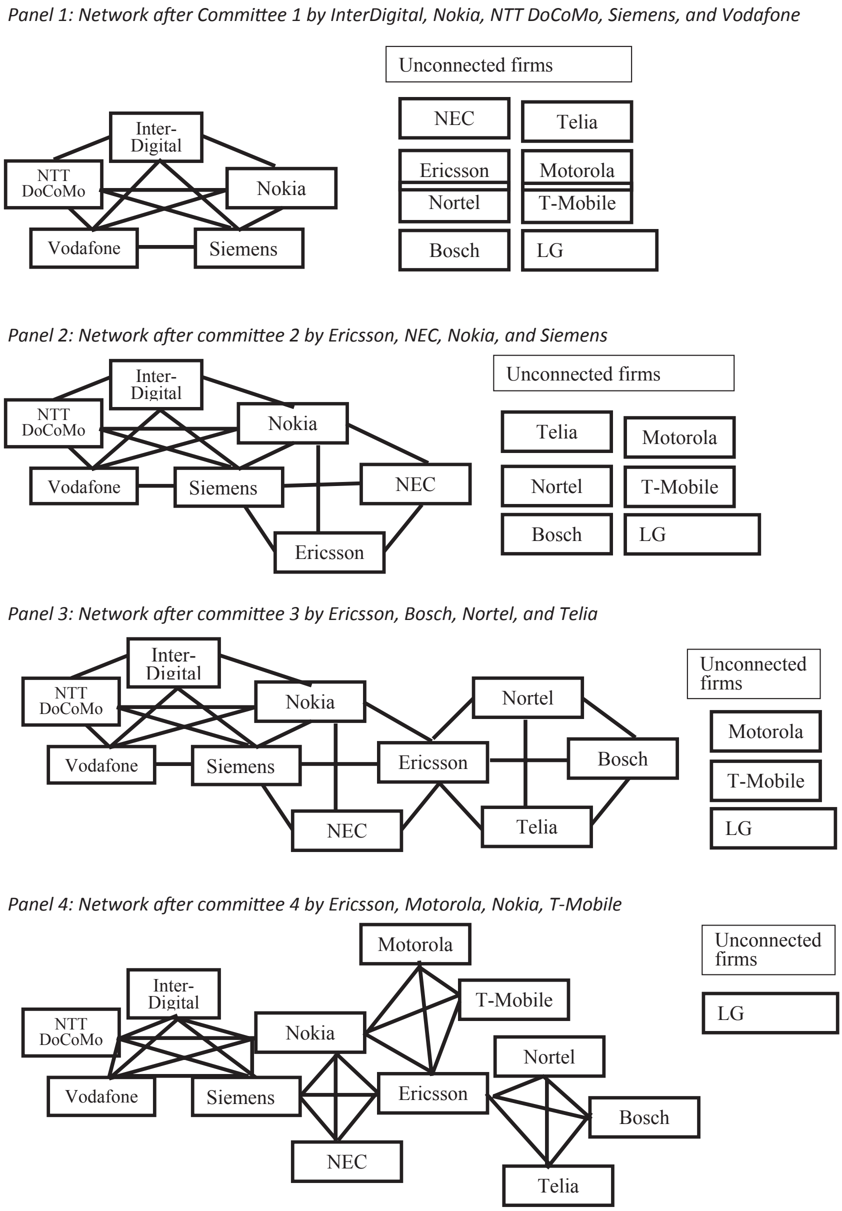

FIGURE 1. NETWORK EVOLUTION

For Motorola, supporting would have resulted in four new direct connections that include the supporters of the $t = 2$ committee. Motorola also would have gained three new indirect connections of length two: $\Delta Connections2_{Motorola,2} = 3$ because the three supporters of the $t = 1$ committee that were not in $t = 2$ committee would have become indirect connections for Motorola (through Nokia).

Figure 2 illustrates the network in the last period of data that we have, $t = 64$. After the formation of committee $t = 64$, the network architecture was quite complex. It comprised of a single component. The longest path between two firms was of length

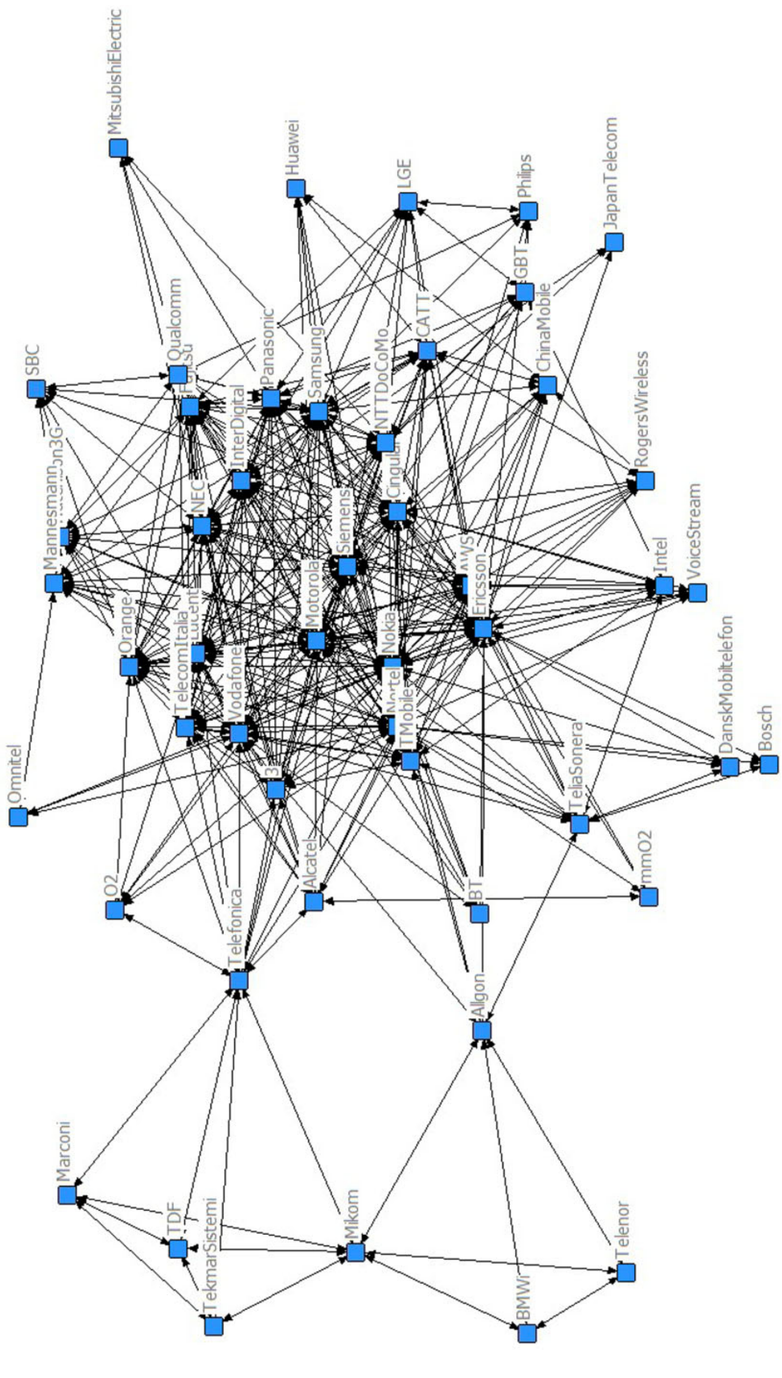

FIGURE 2. THE NETWORK AFTER COMMITTEE $t = 64$ IN THE END OF 2003

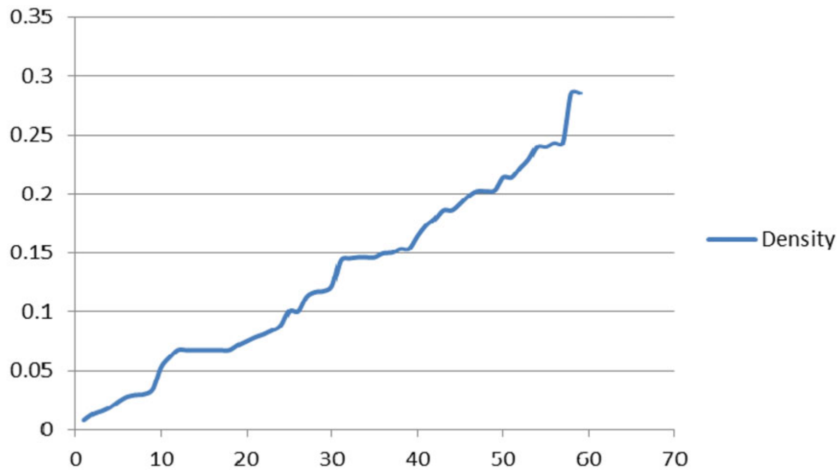

FIGURE 3. EVOLUTION OF NETWORK DENSITY

At the end of the period of study, network density reaches 0.286, in other words, 28.6% of all possible connections among the firms have been formed.

**TABLE I.
DISTRIBUTION OF NETWORK CONNECTIVITY**

Committee network		Firm network		Distribution of degree	
Number of supporters per committee	Number of committees	Number of committees per firm	Number of firms	Degree (one-mode connections to peers)	Number of firms
4	27	1	11	3–5	14
5	12	2–3	9	6–10	9
6	1	4–5	8	11–15	7
7	7	6–10	6	16–20	4
8	5	11–20	5	21–25	7
9	2	21–30	3	26–30	6
10	8	>30	2	>30	3

four. The density of the network, defined as the ratio of all existing direct links to all potential direct links in the network (i.e., to all possible pairs of players), increased. After the last committee $t = 64$, the density reached 0.297. Figure 3 plots the density of the induced social network after each committee was formed.

Table I shows the distribution of supporters per committee and the distribution of committees per supporter. Most committees had four or five supporters, but 10 committees were significantly larger and had nine or ten supporters.[5] Similarly, most firms supported five or fewer committees over the 4-year period, but the most active firms, also listed in Table II, engaged in over 30 work-item committees. As a result of this cooperative activity, in the end of the period, most firms have fewer than 10 direct network connections to peers, whereas the most connected firms have over 30 direct connections.

5. Larger committees appeared in various points in time. The first nine-supporter committee was formed in period $t = 11$, and the last was formed in period $t = 64$.

Table II.
Top 15 Firms in 3GPP Radio Access Network Work Item Support Committees Sorted by Frequency of Participation, 2000–2003

Firm	No. of work item committees supported	Home country	No. of employees (2003)	No. of essential IPR declarations
Ericsson	34	Sweden	51,583	1,124
Siemens	33	Germany	417,000	1,122
Nokia	32	Finland	51,359	5,644
Motorola	23	United States	88,000	1,682
Nortel networks	23	Canada	35,160	8
Vodafone	20	United Kingdom	60,109	15
Samsung	16	Korea	88,447	2,220
InterDigital	15	United States	320	1,003
NTT, NTT DoCoMo	14	Japan	205,288	0
Panasonic	13	Japan	16,685*	0
Fujitsu	10	Japan	157,044	0
NEC	10	Japan	143,393	0
AT&T wireless	9	United States	31,000	0
Cingular wireless	9	United States	39,400	0
T-Mobile	9	Germany	43,427	0
Means				
Top 15 contributors	18.00		95,214	854.53
The estimation sample of 44 firms	8.02		71,092	405.34

*Panasonic's employee count is from 2001. Essential IPR declarations are the total for 2000–2003.

However, no firm is connected to all other firms, and, in the end, there remain several shortest paths of length four.

The most frequent contributors to the 3GPP committee work are listed in Table II. The top three firms on the list are major European technology vendors, pointing to the European origins of 3GPP, but a clear majority of the fifteen most active contributors are Asian or North American. With the exception of InterDigital, these companies are large telecom equipment vendors or operators.

There is great variation in terms of essential IP declarations made by work-item contributors (Table II). Most firms declare no patents, whereas the IP leaders in the group (Nokia, Ericsson, Motorola, and Samsung) have declared that they have hundreds of patents that may be related to some standard specifications. It is noteworthy that Qualcomm, a firm that had over 200 essential IP declarations, was not among the most frequent contributors (its work-item contributions are below sample mean). Clearly, it followed a different cooperation strategy than Nokia, Ericsson, and Motorola.

Burt (1992, 2004) proposes that firms gain social capital from holding brokerage positions—positions that fill "structural holes," connecting firms that are otherwise disconnected or connected only with long paths. Burt suggests that a broker can learn and be exposed to alternative ways of thinking that originated in different parts of the network. Burt's summary measure of (the converse of) brokerage is called network constraint. Constraint is high for a node that is connected to others who are connected to each other, or connected through a well-connected node, in other words, a node that is not bridging a structural hole (Burt, 2004, p. 14). In Table II, we include firms' network

Table III.
Variables and Descriptive Statistics ($N = 2728$)

Variable	Description	Mean	Std. deviation	Min	Max
WI supporter	Binary variable = 1 if firm supported work item *t*	0.122	0.327	0	1
WI source	Binary variable = 1 if firm proposed work item *t*	0.029	0.167	0	1
Δ*Connections*1	Potential change in direct connections from WI committee *t*	4.03	2.31	0	9
Δ*Connections*2	Potential change in 2-degree connections from WI committee *t*	4.16	9.67	−8	38
Δ*Connections*3	Potential change in 3-degree connections from WI committee *t*	0.15	4.74	−35	30
WI duration	The duration of work-item committees (months)	12.838	9.548	0	63
Technological distance to source	Euclidean patent portfolio distance from firm *i* to the firm proposing the work item *t*	0.644	0.354	0	1
Employees	Number of employees (annual)	77,397	88,279	20	450,000
Size1–Size6	Six sample quantile dummies of firm size (annual)				
US patent	Patents granted at the US PTO (annual)	324.55	507.10	0	2,111
EPO patent	Patents granted at the EPO (annual)	63.56	141.54	0	1,197
JPO patent	Patents granted at the JPO (annual)	549.69	1833.99	0	12,571
Essential IP	Essential IP declarations (annual)	6.38	27.74	0	264
Representatives	Binary variable = 1 if firm had representatives in 3GPP RAN meetings	0.680	0.467	0	1

Note: Firm size, IP variables, and representatives are observed annually. Work-item duration information is available for 37 work items only.

constraints to highlight information brokerage opportunities in our sample. High values of the constraint imply few brokerage opportunities. In the final network created after the last work-item committee was formed (see Figure 2), the network constraints of firms ranged from 0.193 to 0.942. Table II displays the constraints in the final network for the most frequent contributors to the 3GPP committee work. These data show that work-item activities allowed leading firms to achieve strong brokerage positions. The average network constraint for the group of frequent contributors is 0.227 compared to 0.416 for all firms. However, we note that supporting a committee does not necessarily lower a firms' network constraint. For example, a firm that supports a single committee that is disconnected from the main component would retain the maximal level of constraint equal to one. Indeed, it is interesting to observe that most committees were formed so as to immediately become connected to the main component. This may reflect firms' attempts to benefit from brokerage.

The estimation sample consists of firms that supported at least one work-item committee and for whom additional information is available. Table III displays the descriptive statistics for these 44 firms and their 64 consecutive work-item decisions, excluding the committees with 3 and 18 supporters, resulting in 2,728 observations. Pairwise correlations of the estimation variables are provided in Table AI. The dependent variable is WI supporter, which is a binary variable equal to one if firm i decided to support work-item committee t. Source is the firm that initially proposed a specific work item, and, arguably, significantly influenced the content of the work item and the composition of the work-item committees. For some committees there is more than one source. Information about work-item sources is used to form the technology distance variable. Table III also features the $\Delta Connections$ variables that describe the potential changes in a firm's network connections should it decide to support the current work item. Note that the $\Delta Connections2$ and $\Delta Connections3$ variables can take negative values because an indirect connection can change into a direct connection or into an indirect connection with a shorter path length as a result of the formation of new connections when supporting a work-item committee.

To assess technological complementarities between committee supporters and sources, we construct a measure of the technological relationship between each firm and the work-item sources. We argue that by focusing on the relationships between the sources and constituent committee supporters we get a reasonable view into the R&D composition of the committee, because the work-item sources are typically the leaders driving the feature. The identity of the source is known at the time the firm chooses whether to support. We consider 15 key wireless telecommunications patent classes and define each firm's patent profile as the share of U.S. patents it has in each class out of its total holdings in the 15 patent classes. We then find firm i's technological distance to the work-item source as defined by the Euclidean distance between their patent profile vectors. This will measure the degree of similarity between each firm and the work-item source in terms of the importance of wireless telecom patent classes in their patent portfolios.[6] The technological portfolio of a work-item source likely describes not only this firm but also the technological nature of the work item this firm proposed. We also note that, whereas relatively few firms have declared essential patents, most 3GPP member firms hold at least some patents in the 15 patent classes we consider when constructing the technological distance measure. Our control variables include a set of binary indicators of firm size and natural logarithms of firms' patents in three jurisdictions—Europe, United States, and Japan. Firm size classes are identified from sample quantiles. Additionally, small privately held firms for which employee information is not available are included in the first group. In the estimations, the class associated with the largest firm size is the reference group. We also have information about firms' holdings of IP that they have declared as potentially "essential" to the standard. Essential IP means that these patented technologies may become part of the standard, in which case other firms may have to pay royalty fees to the firm if they want to implement the standard in their own products. Firms that have declared essential IPRs are thus more likely to have proprietary technology assets related to the current committee. We expect that essential IP declarations reflect potential direct benefits from work-item committees and are therefore strongly associated with committee behavior. We use the natural logarithm of the number of essential IP declarations. All these control variables are observed annually.

As a descriptive analysis of the relationships among explanatory variables and the dependent variable, Table IV provides means and standard deviations for key control variables separately for firms that supported at least one work-item committee and those that never supported any committees. Firms that supported at least one work item clearly differ from the rest of the 3GPP members. On average, they are larger, devote more

6. The Euclidean distance between firms i and j is defined as $E_{ij} = \sqrt{\sum_k (p_{ik} - p_{jk})^2}$, where p_{ik} refers to the share of patents in each class k.

Table IV.
Summary Statistics For Nonsupporting, Supporting, and Source Firms Attending 3GPP Radio Access Network Meetings

	Never supporter	Supporter but never source	Source	All observations
Employees	53,396	63,775	86,978	68,007
Meeting representatives	0.296	0.917	2.13	1.02
Annual US patents	220.90	174.19	438.83	278.63
Annual EPO patents	43.89	36.42	84.19	54.85
Annual JPO patents	1003.54	432.18	638.99	750.76
Annual essential IP	0.006	2.22	9.54	3.55
Work-item committees (2000–2003)	0	4.26	10.88	4.46
R&D services	0	0	0.080	0.025
Components	0.343	0.158	0.160	0.241
Computer and consumer electronics	0.143	0.053	0.080	0.101
Network and terminal equipment	0.143	0.211	0.320	0.215
Telecom operators	0.371	0.579	0.360	0.418
Observations	2,170	1,178	1,550	4,898

Note: Employee numbers are only available for 3 742 observations in total. The above statistics are the means over 2000–2003 for firms in each category. The group "never supporter" includes firms that were members of 3GPP and attended some RAN meetings over the period of study but did not support any work items.

Table V.
Summary Statistics Per Work Item Committee

Variable	Mean	Std. deviation	Minimum	Maximum
Number of supporters	5.71	1.96	4	9
Number of different industries	2.50	0.74	1	4
Number of small firms	0.79	0.73	0	2
Patents held by supporting firms	20,887	8,849	4	36,483
Number of different patent classes by supporting firms	14.79	1.53	3	15
Total number of essential patents declared 2000–2003 by supporting firms	5,585	3,359	0	11,807

Note: Small firms include firms smaller than the median firm.

resources to standard setting as measured by the average number of representatives in each meeting, and have more patents in all jurisdictions and more IP declared as essential for 3GPP standards. Firms that acted as sources of new work-item proposals are even larger than other firms who supported work items, and have an even greater interest in standard setting, evident in the larger number of meeting representatives. To a significant degree, this interest may be driven by their IP holdings. Finally, we note that in the Radio Access Network technical specification group of 3GPP, equipment vendors and telecommunications operators carry a disproportionate load in participating in work-item committees and proposing new ones.

Table V displays our last set of descriptive statistics, now at the level of work-item committees. On average, work-item committees have about six supporters (including the source/s) from 2.5 different industries. Usually one of the supporters is a small company, defined as belonging to the smallest third of the sample in terms of number of employees. There are no committees consisting entirely of supporters without any patents, and most committees have some supporters with large and diverse patent portfolios. However, some committees do not include any supporters that have declared essential IP.

5. Regression Analyses

5.1 Empirical Model

We empirically examine firms' decisions to support work-item committees in a panel data framework. To address our question of whether networking considerations influence firms' decisions to support work-item committees, we include a vector of variables representing changes in firms' direct and indirect connections should they support the current work item, $\Delta Connections = (\Delta Connections1, \Delta Connections2, \Delta Connections3)$. To address the question of whether firms seek technological complementarities we include the technological distance variable representing the relationship between the firm and the source of the work item.

To control for other possible explanations for supporting work-item committees we include additional variables that may affect the decision to support. First, as suggested in earlier work, it is possible that firms seek opportunities to insert proprietary intellectual assets into the standard specification so that others have to pay royalties. Firms with essential IP may thus receive higher direct benefits from work items. We control for this with a vector of IP variables entered in natural logarithms.

Second, to support a work-item committee, firms need to devote human resources to work-item development. Small firms are more likely to be resource constrained, and committing skilled engineers to specification development work may be more costly to them. Hence, we include firm size dummies and a variable that reflects the number of meeting representatives to directly control for firms' standard-setting resources. Finally, we include firm fixed effects γ_i. Firm-level fixed effects allow us to account for firm-specific time-invariant determinants of participation. We also include work-item fixed effects ψ_t. These capture the attractiveness of a certain work-item committee on average. Because work items are formed sequentially, these also replace time dummies. We do not include meeting dummies in specifications with work-item committee dummies as they cannot be separately identified. However, our results are robust to replacing committee dummies with meeting dummies.

The main specification of our empirical model can be written as follows:

$$\Delta u_{it} = \alpha + \beta_1 Size_{it} + \beta_2 IP_{it} + \beta_{3t} Technological\_distance + \beta_4 \Delta Connections_{it} + \gamma_i + \psi_t + \varepsilon_{it}. \quad (1)$$

Observations are indexed with $i = 1, \ldots, 44$ (firms) and $t = 1, \ldots, 64$ (work items). As the empirical dependent variable is binary, the above equation can be written in terms of a latent variable Δu and the observed binary variable Δu^*:

$$\Delta u_{it} = x\beta + \gamma_i + \psi_t + \varepsilon_{it}, \quad (2)$$

$$\Delta u^*_{it} = 1[\Delta u_{it} > 0].$$

In other words, we should observe a firm supporting a work-item committee when the net benefits are greater than zero. To estimate the parameters of the empirical model we apply standard panel-data estimation techniques for binary outcomes. For most models, the Hausman test rejects the random-effects approach, especially when

$\Delta Connections$ variables are included. Hence, we primarily rely on conditional logit and linear probability fixed-effects models.

Identification of the effects of social interactions is often subject to the so-called reflection problem. Manski (1995, p. 129) explains that "the reflection problem . . . arises when the researcher observes the distribution of behavior in a population and wishes to infer whether the average behavior in some group influences the behavior of individuals that compose that group." Our empirical model does not rely on peer group averages of the dependent variable, thus the collinearity problem that Manski describes does not arise.

We observe the same firms repeatedly deciding whether to support emerging work items, and also observe multiple firms' decisions to support the same work item. This richness of the data allows us to include in the empirical analysis both firm-level fixed effects and work-item fixed effects. These alleviate concerns about unobserved heterogeneity influencing firms' decisions to support work-item committees. Firm fixed effects capture permanent unobserved firm characteristics that can affect their decisions to support work items, and work-item fixed effects control for unobserved characteristics of the work-item project as well as its source.

One concern in identifying the effects of new indirect connections is that what may seem to be a desire to link to a well-connected firm might actually be an attraction to that firm's unobserved characteristics. By including committee fixed effects we are able to control for the average characteristics of the committee supporters. We identify the effect of new indirect connections because they vary across all other firms.

Another potential source of identification problems could be the simultaneous nature of firms' decisions to support each work-item committee. We address this concern by estimating an instrumental variable model. For each firm and in each period, we draw a random five-supporter committee (the median committee size is five). For each firm i and period t, we use the actual committees up until time $t-1$ and replace the work item of period t with a randomly generated committee. The number of new direct connections to the supporters of the random committee instruments for the number of new direct connections from the committee t in the actual network. The number of new indirect connections of path length two and three induced by the potential supporting of the random committee instrument for the number of new indirect connections in the actual network.[7] These instrumental variables are strongly correlated with the actual new connection variables, because they reflect the overall pattern of evolution of the network. However, they are not correlated with the error term because they are not associated with the unobserved characteristics of the specific actual committee t. In other words, connections to the random committee capture the general "connectedness" of each firm in period t, and thus strongly and significantly explain the firm's actual pattern of connections, but any firm's connections to firms in the randomly generated committee do not correlate with the firm's unobserved interests in connecting specifically with firms in the actual committee, or with the unobserved choices of other firms in period t. Hence, we expect these instruments to be valid. They are also very strong, as their F-statistics in the first-stage equations are all above 40. We use these instruments in a standard two-stage least squares model of the linear probability of supporting work-item committees.

7. We thank John Ham for suggesting the use of random committees to generate instruments.

5.2 Estimation Results

We examine the effects on the decision to support work-item committees of potential changes in network connections and the firm's technological distance to the source. We had no clear prediction on the effect of new direct connections; the sign of this variable will reveal the balance between costs and benefits. In contrast, we hypothesized that because firms enjoy information benefits from indirect connections to peers but these do not add to the network costs, all else equal, indirect connections have positive effects.

We present the results of our regression analyses in Table VI. In specifications 1 and 2, we report results concerning firms' potentially changed connections to the other supporters of the current committee, without work-item fixed effects. Specifications 3 and 4 include work-item fixed effects. We consider both the linear probability model and the conditional logit model. The linear model also utilizes clustering of the standard errors at the firm level. The results from the two methods are qualitatively aligned. All specifications include firm fixed effects, as well as firm size and IP holdings which have time-varying firm effects. Whereas in Table IV we observed a strong positive correlation between firm size and the decision to support work items, in Table VI (where firm fixed effects are included) we observe no significant effect of size on the decision to support. The IP control variables are usually not significant either.

The estimated effects of $\Delta Connections1$ are consistently and significantly negative. This variable reflects the net effect of making new direct connections. According to these estimates, holding all else constant, the costs of new direct connections exceed their benefits. On the other hand, for each firm, supporters of a specific work item that are not new direct connections are, by definition, existing connections from earlier work item collaborations. Thus, as we include work item fixed effects, the negative effect of $\Delta Connections1$ may also reflect the positive effect of continued collaboration with existing connections. Indeed, in specifications not reported in the table, we included the variable reflecting existing connections to the supporters of committee t, and it obtained a strong and statistically significant positive coefficient.[8] As we expected, potential changes in indirect connections of path length two ($\Delta Connections2$) have a consistently significant and positive coefficient. The coefficient of $\Delta Connections3$ reflecting changes in indirect connections of path length three is less robust and can vary depending on the estimation method or other variables included in the model. In terms of the magnitudes of these effects, the coefficients in column 4 suggest a 77% decrease in the odds of supporting a committee for each new direct connection and a 17% increase in the odds of supporting for a new indirect one. The equivalent linear probability model in specification 3 suggests a decrease of 0.11 in the probability of supporting a committee with every new direct connection and an increase of 0.008 in the probability of supporting with an additional indirect connection. For the low levels of overall probability of supporting in our data set (the raw probability of supporting is 0.12 in our sample, see Table III), the risk differences and odds ratios are reasonably aligned. Moreover, both estimation methods suggest that in order to justify making a (costly) new direct connection, firms should gain several new indirect connections. In other words, firms are likely to form new direct connections to well-connected firms.

Finally, all models include the measure of technological distance between the focal firm and the work-item sources (the firm or firms that initially proposed it). We excluded

8. It is not possible to estimate the effects of both existing and new direct connections in the same model, when work item fixed effects are included, however, in a model that excludes fixed effects we observed a positive effect for existing connections and a negative effects of new direct connections.

Table VI.
Estimation Results

	(1) Linear fixed-effects regression		(2) Conditional fixed-effects logit			(3) Linear fixed-effects regression		(4) Conditional fixed-effects logit			(5) 2SLS	
	Coef.	SE	Coef.	SE	Odds ratio	Coef.	SE	Coef.	SE	Odds ratio	Coef.	SE
Main variables of interest												
ΔConnections1	−0.042***	0.006	−0.629***	0.055	0.533	−0.106***	0.006	−1.478***	0.118	0.228	−0.100***	0.014
ΔConnections2	0.003***	0.001	0.069***	0.017	1.072	0.008***	0.0008	0.160***	0.021	1.173	0.007***	−0.002
ΔConnections3	−0.000	0.001	0.084**	0.036	1.088	−0.004*	0.002	0.059	0.041	1.061	−0.002	0.002
Technological distance to source	0.254***	0.052	2.271***	0.279	9.693	0.056	0.039	1.076***	0.727	2.933	0.039	0.025
Control variables												
Size1	0.022	0.073	−1.021	1.293	0.360	0.016	0.065	−0.770	1.409	0.463	0.0003	0.020
Size2	0.046	0.066	0.299	0.484	1.349	0.024	0.055	−0.042	0.605	0.959	0.006	0.021
Size3	−0.002	0.043	−0.130	0.365	0.879	−0.005	0.040	−0.024	0.437	0.977	0.012	0.021
Log(US patent)	−0.008	0.021	−0.389	0.337	0.678	−0.019	0.019	−0.670*	0.393	0.512	0.006	0.004
Log(JPO patent)	0.005	0.012	0.085	0.173	1.088	0.013	0.012	0.318	0.220	1.374	0.002	0.005
Log(EPO patent)	0.021	0.022	0.145	0.127	1.156	0.009	0.018	0.096	0.194	1.101	0.005	0.007
Log(essential IP)	−0.005	0.008	−0.058	0.081	0.943	−0.001	0.011	−0.039	0.098	0.962	0.005	0.007
Representatives>0	0.010	0.015	0.132	0.251	1.141	0.002	0.018	0.623	0.408	1.865	0.010	0.014
Constant	0.075	0.086				0.587***	0.111				0.535***	0.074
R^2	0.071					0.348						
Log likelihood			−496.7					−365.7				
Observations	2650		2468			2650		2468			2650	

Notes: Dependent variable is WI supporter. Firm size class 4 that includes the largest 33% of firms is the omitted size group. Models 1 and 3 are estimated with linear fixed-effects regression clustering standard errors; models 2 and 4 are estimated with conditional fixed-effects logit. Model 5 is estimated with 2SLS using each firm's connections to randomly generated 5-member committees as instruments for ΔConn1, ΔConn2 and ΔConn3. *F*-statistics of the instruments are all greater than 40 and the Kleibergen–Paap or Cragg–Donald tests for weak identification do not suggest problems with weak instruments. All specifications exclude observations where the focal firm was the work-item source. Specifications 3–5 include work-item fixed effects and specifications 1–4 include firm fixed effects.
***implies statistical significance at the 1% level, ** at the 5% level, and * at the 10% level.

the observations where the focal firm was the work-item source. This way we get a clear view into firms' decisions to support other firms' proposed work items. The technological distance variable obtains a highly significant and positive coefficient in three of the five specifications.[9] These results suggest that firms are more likely to support work-item committees where they are technologically different from the source firms. We thus find some evidence of technological complementarities in the inputs different firms provide in the committee, rather than technological rivalry at the committee level.

In specification 5, we estimate the two-stage least-squares model with instruments generated from a stream of random five-firm committees. These results are not substantially different from those in specification 3 and suggest that most of the unobserved effects on work-item committee participation are already accounted for with the firm and committee fixed effects.

5.3 Additional Tests

We tested for a number of alternative explanations for supporting work items: committee size, the number of patents held by the other committee supporters, the number of essential patents held by them, the diversity of their patent classes, and the technological distance to the other supporters. Most of these variables are intended to capture the technological characteristics of the work item and its supporters. However, none of the additional variables had noticeable effects in the coefficients of the main variables of interest and most of them had insignificant coefficients. In particular, our attempts to capture the effects of technological distance to other committee supporters did not gain any explanatory power. Our findings were also robust to the exclusion of the first 20 work items. Hence, the fact that initially the network is sparse (the network is empty at $t = 0$) does not drive the results. The results are similarly robust to the exclusion of the last 20 work items. Hence, the fact that the network becomes a denser single component is not driving the results.

We also checked whether the results on network variables are influenced by multicollinearity—the connection variables are rather strongly correlated. We found that excluding $\Delta Connections1$, $\Delta Connections2$ retains its positive and significant coefficient ($\Delta Connections3$ turns positive and significant). Similarly, excluding $\Delta Connections2$, $\Delta Connections1$ retains its negative and $\Delta Connections3$ its positive coefficient, and the latter turns statistically significant.

We conducted several additional robustness checks by splitting the sample in various ways: holders and nonholders of essential IP; small and large firms; and firms with more than eight and less than eight (the mean value of) committee participations. We found no significant differences in the effects of new network connections between these subsamples. The results on the effects of the network variables on the probability of supporting work items are thus remarkably stable across the different types of firms in the sample. We also examined the possibility that firms in different industry segments behave differently in the interorganizational network. Although there are some industry specificities in the effects of potential network connections on firms' decisions to support work-item committees, these appear to be highly correlated with the average firm sizes in these industries. In particular, (small) R&D service providers benefit the least from the

9. If we measure the average distance from the focal firm to all other supporters instead of to the work item source, the estimated coefficient is not significant.

interorganizational network, whereas (large) equipment providers and computer and consumer electronics firms benefit the most.

6. Conclusions

This empirical study proposes a novel perspective on firms' motivations to contribute private resources to the creation of a public good in a standard setting organization. Firms benefit from the social network created by cooperation in standard-setting committees. Our results demonstrate that firms value connections with peers and seek to improve their positions in the interorganizational network. Connections can be beneficial for learning about new technologies and rivals' strategies and for generating opportunities to advertise capabilities or expertise to potential clients.

Firms tend to work with and reinforce preexisting connections, but they benefit from new connections to partners who are well connected: new indirect connections substantially increase probability of supporting a committee. In our data set, effects of network connections are more significant than the effects of IP and market power that have been emphasized in earlier literature. Nevertheless, most of the variation in the data is explained by firm and work-item committee fixed effects—firms' permanent characteristics that drive their strategic choices, and work items' unobserved technological nature. Most specification development is supported by the core group of large firms. The resulting central network positions of these active participants may further reinforce their dominance, but smaller firms occasionally contribute and thus benefit from the information exchange.

Committee composition also influences firms' decisions to support. Firms appear to attach a greater value to a work-item committee if their technological inputs are different from the firms that originally proposed the work item, and if the committee consists of firms from a diverse set of industries. These findings suggest that firms are attracted by technological complementarities. They also challenge the extant view that formal standard setting is largely characterized as a competition to insert proprietary IP in standard specifications. Firms do not tend to support committees populated by firms similar to themselves. Nevertheless, intense technological competition may play out at the level of work-item sources, where source firms, possibly each associated with a clique of supporting firms, may compete to propose technological features beneficial to them. Analysis of this level of competition is left for future work.

To conclude, our study contributes to the literature on cooperative standard setting by highlighting novel explanations for participation and to the literature on interfirm social networks by proposing a novel empirical operationalization for the study of network evolution. Our results suggest that managers should pay attention to the strategic information exchange opportunities in cooperative industry organizations, and that policy-makers may potentially exploit firms' strategic networking behavior in building industrial public goods. However, standard-setting processes may require regulatory oversight and clear rules of the game to prevent capture of the public good by private interests.

Appendix

Table AI. Correlations of the Estimation Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 WI supporter	1													
2 source	0.400*	1												
3 size1	–0.133*	–0.020	1											
4 size2	–0.017*	–0.021	–0.355*	1										
5 size3	–0.134*	–0.083*	–0.307*	–0.202*	1									
6 size4	0.048*	–0.020	–0.476*	–0.313*	–0.271*	1								
7 us patent	0.156*	0.040	–0.450*	–0.144*	0.165*	0.488*	1							
8 jpo patent	–0.002*	0.020	–0.219*	–0.130*	–0. 094*	0.424*	0.501*	1						
9 epo patent	0.172*	–0.019	–0.321*	–0.139*	–0.017	0.458*	0.594*	0.165*	1					
10 essential IP	0.156*	0.142*	–0.046*	0.111	0.186*	0.006	0.140*	–0.030*	0.168	1				
11 representatives	0.150*	0.101*	0.135*	0.022	0.111*	0.042	0.143*	0.152*	0.032	0.112*	1			
12 ΔConnections1	–0.366*	–0.183*	0.154*	0.042*	–0.175*	–0.052*	–0.211*	–0.026	–0.192*	–0.165*	–0.242*	1		
13 ΔConnections2	–0.109*	–0.053*	0.157*	0.077*	–0.167*	–0.078*	–0.254*	–0.018	–0.193*	–0.090*	–0.210	0.354*	1	
14 ΔConnections3	0.014	–0.010	0.135*	–0.137*	–0.018	–0.008	–0.058*	–0.011	–0.082*	–0.016	0.074	–0.051*	0.242*	1
15 technol. distance	–0.115*	–0.261*	0.324*	0.037*	–0.211*	–0.242*	–0.327*	–0.149*	–0.228*	–0.175*	–0.236*	0.370*	0.148*	0.054*

*Implies significant correlation at the 99% level of confidence.

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