

# Below the Tip of the Iceberg: The Co-evolution of Formal and Informal Interorganizational Relations in the Wireless Telecommunications Industry

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We examine how alliances—formal, contractual interorganizational relations—co-evolve with emergent, informal interorganizational relations. To form alliances, firms must acquire information on potential partners, and the acquisition of this intelligence occurs through both formal and informal channels. Here we evaluate the effects of two of these informal channels: joint participation in cooperative technical organizations (CTOs) and director interlocks. Since director interlocks connect firms through the highest managerial levels while joint CTO participation connects firms through mid-level technical personnel, we examine whether each type of informal tie contributes to alliance formation as well as whether ties at multiple levels serve as complements or substitutes for this purpose. We also examine whether all types of ties—alliances, interlocks and CTO participation—co-evolve endogenously or whether there are more direct causal relationships between and among these various types of networks. We find that both interlocks and CTO participation facilitate alliance formation, yet interlocks only facilitate alliance formation when the common director serves as an officer in one of the firms. An additional distinction between the role of interlocks and CTO participation is that the relationship between interlocks and alliance formation appears endogenous, in contrast to CTO participation, which causally precedes alliance formation. Copyright © 2008 John Wiley & Sons, Ltd.

## INTRODUCTION

Interorganizational networks are pervasive in dynamic and technology-driven industries. Industries characterized by a high level of competitiveness and short cycles of innovation put firms into vulnerable strategic positions (Eisenhardt and Schoonhoven, 1996, p. 137) and generate the need

to spread risk and acquire additional resources and competences through the formation of strategic alliances. Powell *et al.* observed empirically that the importance of R&D in an industry is strongly correlated with the number of alliances formed between firms (1996, p. 116). This finding underlines the perception that firms in technologically complex industries, such as the cellular industry, face pressure to find alliance partners in a timely manner.

The literature on interorganizational alliances has highlighted the strategic or resource needs of

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firms to attain new assets and learn new skills (Kogut, 1988; Hagedoorn and Schakenraad, 1994; Powell *et al.*, 1996) and the difficulty of assessing a potential partner's reliability, capabilities and needs (Gulati, 1995). This view on alliance formation stresses the advantages and pitfalls of interorganizational cooperation, but neglects to include the availability of alliance opportunities as a factor. Before a firm can evaluate the strengths and weaknesses of a potential collaboration partner, it has to become aware of the opportunity to collaborate. Since collaboration opportunities are not readily available to all firms in an industry, firms only become aware of these opportunities if they are communicated to them—communication directs firm attention to discriminate among potential opportunities (Ocasio, 1997). The communication of these opportunities takes place through various types of interorganizational channels. Some firms are better connected to their peers than others and therefore can choose their alliance partners out of a larger pool of potential candidates. Likewise, firms that have a central position in an industry gain visibility and are more likely to be chosen as an alliance partner by other firms. The focus on collaboration opportunities basically stresses the importance of communication between firms. Capabilities and needs of firms are not self-evident, but have to be communicated to the right audience at the right time. This interorganizational communication of needs and capabilities occurs through both formal (i.e., contractual linkages such as alliances) channels as well as informal ones. Both formal and informal interorganizational relations serve as arenas where boundary spanners can exchange corporate information.

Studies of alliance networks have demonstrated the endogeneity of these networks—characteristics of the network at one point of time are strong predictors of subsequent characteristics of the networks (Gulati and Gargiulo, 1999). These approaches stress the path dependence of network evolution. Once a firm can rely on extensive experience from past alliances, it improves its potential for subsequent alliance formation. This is an accumulative process; the network reproduces and reinforces itself. While prior alliance experience is an important information resource for managers to assess the capabilities and reliability of potential alliance partners, this view neglects alternative information channels and leaves little room to explain how not-yet-established firms enter an alliance network. Access would only be

possible with extremely superior technological capabilities (Ahuja, 2000a) or with the patronage of an already established firm (Podolny, 1993).

It is obvious that a firm does not communicate as a unitary actor; rather, individual managers and employees belonging to a given firm exchange information. As a consequence, recent articles have paid more attention to the influence of interorganizational networks spanned by individual managers and their effects on alliance formation. Alliance formation is just the tip of the iceberg, which rests upon a large hidden body of more informal interorganizational relations. Such work is critical because it suggests strategic actions that managers may undertake in order to affect the dynamics of alliance networks to the advantage of their firms (Ahuja, 2001). Domains of interest here include top-level contexts such as executive mobility (Eisenhardt and Schoonhoven, 1996) and director interlocks (Gulati and Westphal, 1999), as well as the mid-level context of industry-wide technical committees (Rosenkopf *et al.*, 2001). Studies of this sort show that strategic executive recruitment, director selection and allocation of engineers to technical committees enable knowledge flow, directs attention, and increases goal similarity between firms that are 'linked' through hiring, common directors or participation in technical committees. In turn, the mechanisms of knowledge flow, attention and goal similarity increase the likelihood of alliance formation.

In this spirit, our study examines the effect of two informal interorganizational relations (technological communities and director interlocks) on alliance formation in the telecommunication sector. We chose the telecommunication sector as a context for our study for several reasons. During the time frame of our study, between 1990 and 1995, the cellular industry grew at a rapid pace in terms of revenues as well as subscribers. On the technological front, the dominant analog cellular service was challenged and finally substituted by digital technology; e.g., Qualcomm's code-division multiple access technology in 1993, which expanded the bandwidth by 10 times and more. The effort to develop a suitable protocol for that technology to enable the operation of hand-held devices overshadowed the latter half of our study period. As a consequence, the industry demonstrates a high degree of interorganizational coordination and negotiation, which manifests in alliance formation and Co-operative Technical Organization (CTO) participation.

We assume that more formal relations like the formation of alliances, which are explicit and contractual, are primed by informal relations like director interlocks and joint CTO participation. We conceptualize technological communities and director interlocks as informal informational environments, which serve firms as 'pre-alliance' contexts. We term these two contexts 'informal' because there is no explicit contract between the two firms linked by these mechanisms; rather, the links for information flow emerge from separate decisions by each firm to participate in technical committees or to name directors. These 'pre-alliance' contexts make firms aware of potential interlock partners and allow them to assess the capabilities and intention of those potential partners. We analyze if these two 'pre-alliance' networks serve as complements to and/or substitutes for each other with respect to subsequent alliance formation. More specifically, we question whether both top-level and lower-level contacts are critical for alliance formation, or whether one level of contacts is sufficient. However, it is also possible, that formal interorganizational relations, in turn, affect informal ones. Therefore, we also consider the potential reverse effect of the network of prior alliances on the formation of director interlocks and the occurrence of joint CTO participation. With this approach, we may discern whether there are clear causal links from the 'pre-alliance' context to alliance formation, or whether the sets of networks are endogenous in that formed alliances also predict subsequent informal 'pre-alliance' networks.

The paper is organized as follows. First, we define the various interorganizational relations that are relevant for our study. After describing the importance of alliances, especially for technology-driven companies, we focus on the influence of director interlocks and CTOs on alliance formation. We also discuss possible endogeneity of these multiple network ties. Subsequently, we support our hypotheses with statistical analyses and draw conclusions from these findings in the Discussion section.

### FORMAL AND INFORMAL INTERORGANIZATIONAL RELATIONS

Especially in technology-driven industries, firms are highly motivated to form alliances. Systemic technologies depend on the compatibility of the

modules which make up the system. Since most companies do not have the financial and technological resources to create a whole system on their own, they have to form close cooperation with other firms in the industry (Tushman and Rosenkopf, 1992; Garud and Kumaraswamy, 1995; Afuah, 2000). In general, collaborative interorganizational linkages have two kinds of advantages for the participating firms. On the one hand, interorganizational resource sharing enables firms to tackle problems and develop solutions that a single firm would not have the resources to do. In this sense, strategic alliances extend the boundaries of a firm. On the other hand, knowledge spillovers generated by strategic alliances add to the individual organizations knowledge stock (Ahuja, 2000). In general, interorganizational linkages help firms 'to develop and absorb new technology, withstand environmental shocks and improve survival chances and financial performance' (Ahuja, 2000b, p. 318).

However, even if from the strategic point of view of a firm it is obvious that an alliance partner is needed, the firm still has to find the right match. The need to join forces does not solve the problem of with whom to form an alliance. While exogenous factors like the distribution of technological capabilities and the structure of resource dependence may determine the need to form an interorganizational tie, this information does not specify with whom to tie and to what extent. Firms have to actively engage in a search for potential partners and have to assess each others' competences, needs and reliabilities. This information is difficult to attain without having direct in-depth contact to those firms in question. They are, however, vital for a productive and successful relationship and to make opportunistic behavior unlikely.

One approach to circumvent this information bottleneck is to repeat what worked in the past. Additional ties to previous alliance partners are likely to develop in a self-reinforcing network process of alliance formation (Gulati and Gargiulo, 1999). However, this strategy only works for firms with extensive alliance experience under comparable business conditions. Lack of experience and changing business conditions increase the importance of alternative informational sources. Eisenhardt and Schoonhoven (1996) show that the external social relations of a well-connected top management team facilitate the

formation of strategic alliances. Similarly, director interlocks can serve as an informal venue of information transfer on capabilities and interests of other firms (Gulati and Westphal, 1999). Finally, participation in standard setting communities allows firms with little prior alliance experience in an industry to learn about potential alliance partners and make themselves visible to other firms (Rosenkopf *et al.*, 2001). We expect the mid-level as well the top-level information channels to affect the formation of alliances. The following sections explore these two ‘pre-alliance’ arenas. By studying the two venues simultaneously, we can also examine whether they interact with each other.

### Top-level Ties: Director Interlocks

Director interlocks are interorganizational relations that allow for informal information exchange with potential effects on corporate behavior and performance. Researchers have conceptualized interlocks as means of financial cooptation and influence (Pennings, 1980; Burt, 1983; Mizruchi and Stearns, 1988), as arenas of collusion and coordination, as educating executives and providing them with general knowledge about industries (Useem, 1984), or as channels for the diffusion of business practices and norms (Haunschild 1993; Davis and Greve, 1997; for a summary see Mizruchi, 1996).

Several studies suggest that interlocks among large industrial corporations facilitate the diffusion of information about widely applicable corporate practices. Davis (1991) and Davis and Greve (1997) show that director interlocks influence the diffusion of poison pills. A focal firm that is interlocked with other firms, which have adopted poison pills in the past, is more likely to adopt the poison pill subsequently. Similarly, Haunschild (1993) argues that firms imitate their peers’ acquisition activities. Being interlocked with firms that have conducted acquisitions in the past provides the focal firm with important ‘how-to’ information on the one hand and a legitimating rationale on the other. As a consequence, firms that witness a high level of acquisition activity through their linked peers are more likely to conduct an acquisition themselves.

Another focus of interlock research positions the interlock as a mechanism by which one organization can exert direct influence on another.

Some studies show a correlation between the capital dependence of firms and director interlock ties to financial institutions (Pennings, 1980; Mintz and Schwartz, 1981). Mizruchi and Stearns (1988) conducted a longitudinal study with 22 large US industrial corporations from 1956 to 1983. The study found that firms with an increased demand for financial capital are more likely to appoint a representative of an important financial company to the board of directors. These empirical findings suggest that director interlocks serve as a communication channel with an influence on corporate behavior.

Therefore, we would expect that the interorganizational communication channels established by interlocks create the capacity for information about each firm’s resources, capabilities and interests to be shared. Such capacity enables the identification of alliances opportunities by the board member, who can share these insights with other members of top management.

### Hypothesis 1a:

Director interlocks between two firms increase the likelihood of subsequent alliance formation by that dyad.

Gulati and Westphal (1999) directly examine the effect of interlocks on alliance formation. In a study of Fortune 500 firms, they demonstrate that the interlock–alliance relationship obtains when the board and the CEO have a supportive (i.e., consensus-based) relationship, but not when they have a controlling (i.e., contentious) relationship. These findings suggest a contingency for the interlock–alliance relationship that rests on the board member’s ability to communicate information about alliance opportunities and the CEO’s inclination to respond positively to it. While we will not examine the nature of the CEO–board relationship in our study, we pursue the argument that the board member must have an ability to identify alliance opportunities in order to communicate them. Since we focus our study on one particular high-tech industry, the ability to identify technical alliance opportunities in this context may be in large part determined by a board member’s understanding of the firm’s relevant business and technology-related issues.

Therefore, we argue that the decisive factor of whether interlocks facilitate alliance formation is the immersion of a boundary-spanning director in the operative business of a firm and his or her

influence on the executive decision-making process. In some cases, director interlocks are constituted by a boundary-spanning individual who serves as an outside director on each of the two boards of the focal firm dyad. This individual has no operational responsibility at either firm, and we call these types of ties 'neutral' or 'symmetric' interlocks. Yet in other cases, the interlock is constituted by a boundary spanner who is a member of the top executive team in one of the firms. Since this person has operational responsibility, we distinguish this type of tie from the neutral director interlocks by calling them 'director-officer' or 'asymmetric' interlocks (see Figure 1).

Of course, a top executive officer can be an inside director, but need not be. Since the importance of interlocks to our discussion rests on an assumption of knowledge sharing by the boundary spanner, we include interlocks constituted by non-director officers.

In a firm dyad where the boundary-spanning individual is an executive in one of the firms, interorganizational information transfer that makes a difference in corporate action is intensified. While top executive officers can directly use the contact and the information about another firm to actively initiate an alliance, members of the board of directors usually do not have this option. Also, potential distrust between the executive team and the controlling board, as explored by Gulati and Westphal (1999), cannot obstruct information transfer and the exercise of influence in one of the firms. These two reasons increase the likelihood of alliance formation as a consequence of board interlocking. Thus, we expect the effect of interlocks on alliance formation to be driven by these asymmetric interlocks. Hence:

#### Hypothesis 1b:

The positive effect of interlocks on the likelihood of subsequent alliance formation is driven by

asymmetric (director-officer) interlocks rather than symmetric (neutral) ones.

#### Mid-level Ties: Cooperative Technical Organizations

While it seems obvious that influential boundary spanners are likely to be found at the top level of an organization, a closer look also reveals that interorganizational activities like alliance formation are closely related to initiatives by mid-level managers. Rosenkopf *et al.* (2001) explored CTOs as an alternative context for alliance formation, which allow firms with little prior alliance experience to communicate their needs and assess the capabilities of potential partners. They found a strong association between joint CTO participation and subsequent alliance formation in this context. A CTO is 'a group that participates in technological information exchange, decision-making or standards-setting for a community' (Rosenkopf and Tushman, 1998, p. 315). In systemic industries, such as telecommunications, there are institutions with extensive histories and well-established structures. One prominent example is the large number of technical committees housed in the International Telecommunication Union (ITU).

Somewhat analogously to the functioning of director interlocks, the joint CTO participation of two firms creates an interlock between them. In contrast to director interlocks, CTO interlocks are situated on a lower hierarchical level. Here, middle managers rather than top managers serve as boundary spanners. Middle managers are usually closer to the operative business than top executives and, in addition, have a high degree of technological expertise. Also, joint CTO participation enables firms to connect through multiple individuals, due to the character of the associational venue. In contrast, only one person usually serves

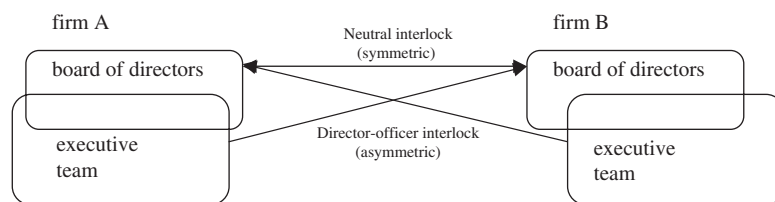


Figure 1. Top-level interlocking possibilities for firms A and B.

as a conduit in the case of director interlocks. Common participation in CTO meetings provides each of the representatives with information on the technological competences of potential alliance partners. The specificity of information on technical competence that is exchanged during CTO meetings is of a different nature than information that is passed along in the context of board meetings. The communication exchanged on a CTO level is likely to be technologically oriented. The discussion in those meetings is about the development and functioning of specific technologies, while conversation on a board level is likely to be more strategy centered.

CTO activity works as an informal interorganizational information venue because it places firms on the 'radar screens' of other firms. Thus, a firm can also use the CTO venue as an opportunity to assess other firms as potential partners. As in many interorganizational domains, information about individuals and their employing firms circulates informally among the participants in this activity. This information serves as context for subsequent decisions about interaction (Powell *et al.*, 1996; Walker *et al.*, 1997), thereby reducing uncertainty for partner selection.

Joint CTO participation can also increase similarity in firms' interests and goals. The shared norms and common language of industry members are enhanced through their continued participation in industry-wide forums. Similar interests and goals lay the groundwork for subsequent collaboration, but equally important is any participant's awareness that particular firms share these goals. Taken together, these mechanisms suggest that CTOs facilitate the identification of both potential partners and specific opportunities for collaboration, which can be formalized subsequently by the formation of an alliance. Such a hypothesis, however, suggests that the alliance formation benefits of joint CTO participation are linearly increasing. While there are benefits of repeated interaction, the marginal benefit of one more common meeting is likely to erode after some point. Hence, the effect of joint CTO participation on subsequent alliance formation is likely to diminish at higher levels of joint CTO participation.

### **Hypothesis 2:**

Joint CTO participation increases the likelihood of subsequent alliance formation at a decreasing rate.

### **CTO Participation and Director-Officer Interlocks: Complementary Networks?**

Clearly, crucial business intelligence is exchanged between firms through various communication channels. Haunschild and Beckman (1998) explored the effect of multiple information channels (director interlocks, business roundtable, business press, consultants, private contacts) on corporate acquisition in four industries. Their results show that information channels can reinforce as well as obstruct each other. For example, the impact of director interlocks on corporate behavior is reduced when alternative information sources like business roundtables are available. On the other hand, business press coverage reinforces the influence of director interlocks on corporate acquisition. The rationale is that while business roundtables essentially provide similar information as a director tie to other companies, business press coverage of acquisition is a complementary information channel to director interlocks in the sense that it increases the awareness of the topic and serves as a primer (p. 840).

Similarly, we expect that director interlocks and joint CTO participation serve as complementary information sources. While director interlocks are most likely to serve as conduits for general information about innovations with widespread applicability, such as poison pills or golden parachutes (Davis and Greve, 1997), they may also communicate basic information such as potential partners of strategic interest or general cooperation opportunities in the industry. In contrast, CTO meetings provide a venue where front-line managers exchange technical information and discuss operational issues of a high degree of specificity. Previous research in the CTO domain has suggested that front-line managers are the ones who develop strategic alternatives and top executives are likely to select from these initiatives (Rosenkopf *et al.*, 2001, p. 748). Top managers are more likely to approve an alliance initiative by front-line managers if they have heard from the company through a different information channel, i.e., if a board interlock relation exists with the focal company. Thus, director interlocks can reinforce the value of collaboration opportunities identified through joint CTO participation.

### **Hypothesis 3:**

Director-officer interlocks increase the effect of joint CTO participation on subsequent alliance formation.

### Endogeneity of Multiple Network Ties

Thus far we have hypothesized that informal interorganizational relationships like joint CTO participation and director interlocks encourage the formation of formal interorganizational relationships like alliances. However, there are no *a priori* theoretic or methodological reasons not to consider other directions of causality. Below, we examine how the multiple interorganizational relations of CTO interlocks, director interlocks and formed alliances may co-evolve.

While director interlocks serve as an active information channel for the formation of new alliances, it is possible that these interlocks emerge as a result of past interorganizational alliances. Firms who have formed alliances in the past are likely to have established connections between various representatives of each firm on several levels. Two firms with an alliance history not only know each other's firm-level resources and capabilities, but they also know about specific human resources in the other firm. Due to the interorganizational coordination and cooperation necessary to form a successful alliance, individuals become known beyond the borders of their firm. Since past alliance formation activity facilitates the prominence of some employees within a firm dyad, the likelihood of a director interlock within this dyad increases.<sup>1</sup>

#### Hypothesis 4a:

Prior alliance formation between two firms facilitates the subsequent emergence of director interlocks between those firms.

A similar argument can be made for the effect of prior alliance formation on joint CTO participation. Alliance formation presupposes a certain degree of strategic alignment and common interests among the participating firms, since resources are invested in a joint project. In the ongoing context of an alliance, the participating firms are likely to influence each other and develop common goals. This increased similarity in interests suggests additional overlap in CTO participation, as each firm chooses to participate in meetings relevant to their goals. It is also plausible that one firm may co-opt representatives from the other firm in the service of what have become shared goals.

#### Hypothesis 4b:

Prior alliance formation facilitates subsequent joint CTO participation.

Coevolutionary dynamics are not only possible between formal and informal interorganizational relations, but also between the two informal ones. Prior joint CTO participation might have the same effect on director interlock formation as prior alliance formation. The engagement in exchange of technological expertise by firm representatives draws the attention to the firms involved. As mid-level engineers become aware of the capabilities of other firms, they can communicate these ideas to top management teams (Rosenkopf *et al.*, 2001). Top management teams, on examining the managerial capabilities of relevant firms, can discover and appoint potential board candidates.

Similarly, director interlocks can facilitate joint CTO participation. Especially, when intra-organizational communication channels between hierarchical levels are well established, an influential and well-informed director could make the difference whether a firm sends representatives to CTO meetings and which meetings mid-level managers attend. If both of the relations hypothesized below are significant, it would show that a lively information exchange between hierarchical levels, the mid-level managers and the top executive team, is going on.

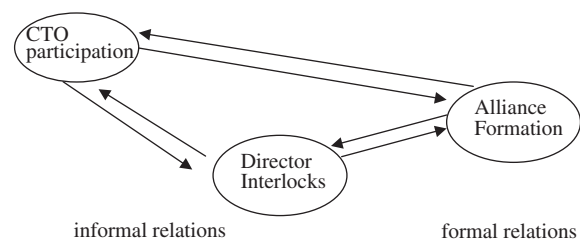
#### Hypothesis 4c:

Prior joint CTO participation of two firms facilitates the subsequent emergence of a director interlock between those two firms.

#### Hypothesis 4d:

Prior director interlock formation facilitates subsequent joint CTO participation.

Thus, the full set of postulated relationships between joint CTO participation, director interlocks and alliances would give rise to the system depicted in Figure 2. We now turn to our analyses to determine how much of this system is borne out by our data.



**Figure 2.** Fully co-evolving networks.

## METHODS

To examine the coevolution of director interlocks and joint CTO membership with alliance formation in the cellular industry, board interlock and CTO participation were collected in the time period between 1990 and 1995, while alliance data were collected from 1988 till 1996. This time period is particularly interesting because of the fast-paced industry dynamics. In the US market, revenues increased from \$4.5 billion to \$19 billion, while capital expenditure rose from \$6.2 billion to \$24 billion. The number of subscribers grew from 5.3 million to 35 million. Additionally, the study period was also in an era of technological ferment. The dominant design, established analog technology, was challenged by digital technology innovations on various fronts.

## DATA SOURCES

The director interlock data for the years 1990–1995 were obtained from Compact Disclosure Database (December Proxies) and the Dun and Bradstreet Million Dollar Database. The databases included information on board directors and executive officers of firms. We retrieved full names and ages so that individuals could be properly distinguished. For all the years, we retrieved 9471 entries on board directors and top executive officers.

CTO participation data were obtained from the *Communications Standards Review* (CSR), a trade publication that summarizes the activities of standards body activity in various telecommunications domains (see Rosenkopf *et al.*, 2001, p. 759).

Alliance announcement data for 1988–1996 were obtained from the Securities Data Corporation database, which lists all joint ventures and strategic alliances worldwide. The database includes agreements where two or more entities have combined resources to form a new, mutually advantageous business arrangement in order to achieve predetermined objectives. Types of alliances covered in the database range from intensive relationships such as joint ventures to arms-length relationships such as licensing and distribution pacts. This information comes from SEC filings and their international counterparts, trade publications, wires and news sources. In our analysis, we focus on alliances that contained a research and development component to insure that they could be realistically associated with the technical professional deliberations in the CTO context. In this category of technical alliances, we do not further distinguish between the strength of the alliance.

## Sample

The sample consists of 87 firms from the telecommunications sector and includes service providers as well as manufacturers of cellular equipment. While we were able to identify 174 firms through the *CorpTech Directory* and the *Million Dollar Directory*, the analysis was limited to 87 firms for which financial data were available.<sup>2</sup> Table 1 summarizes the number of observed interlocks, formed alliances and CTO activity in each year for our 87 firm sample. Over all years, we identified 35 director–director (neutral) ties and 16 director–officer (asymmetric) ties, adding up to

**Table 1. Yearly Counts for Interlock and Alliance Formation for the Sample (out of 87 firms)**

| Year                                      | 1991 | 1992 | 1993 | 1994 | 1995 |
|-------------------------------------------|------|------|------|------|------|
| All dyadic interlock ties                 | 6    | 12   | 7    | 11   | 15   |
| Director–director ties                    | 5    | 7    | 6    | 8    | 9    |
| Director–officer ties                     | 1    | 5    | 1    | 3    | 6    |
| All non-redundant ties                    | 5    | 10   | 6    | 11   | 13   |
| Firms forming technical alliances         | 21   | 25   | 30   | 18   | 24   |
| Total technical (dyadic) alliances formed | 46   | 47   | 74   | 85   | 40   |
| Total dyads in sample                     | 2145 | 2485 | 2701 | 3160 | 3568 |
| Firms participating in CTOs               | 40   | 46   | 40   | 41   | 37   |
| Total CTO meetings held                   | 16   | 19   | 34   | 39   | 47   |
| Average number of meetings attended       | 5.95 | 6.96 | 10.1 | 11.1 | 13.7 |
| Total (dyadic) CTO interactions           | 1774 | 2684 | 2338 | 2807 | 2755 |



a total of 51 board ties. The sample contained 45 unique ties. The number of firms forming technical alliances during 1991–1996 varied between 19 and 30. Over the entire period, 59 of the firms formed at least one technical alliance, while 28 did not form any. The total number of technical alliances formed between firm dyads in each year varied from 40 to 85. In addition, we can observe that CTO activity proliferated over the study period, as the total number of CTO meetings grew from 16 in 1991 to 47 in 1995, and the average number of meetings attended by firms grew correspondingly, from 5.95 in 1991 to 13.7 in 1995.

### Variables

*Technical alliances:* We consider all the technical alliances formed by firms in our sample during the observation period. Strategic alliances are usually defined as ‘any voluntarily initiated cooperative agreement between firms that involves exchange, sharing or codevelopment, and it can include contributions by partners of capital, technology or firm-specific assets’ (Gulati, 1999, p. 397). Technical alliances are the subset of strategic alliances that include an R&D component. Out of all technical cellular alliances listed in the SDC database, we extracted those in which at least two partners were firms in our sample. We constructed measures of dyadic alliances as counts of alliances formed by any two firms in the sample in a given year. Approximately 13% of the alliances recorded included more than two firms; the maximum number of firms in an alliance was six. In the case of alliances that involved more than two firms, we counted the alliance as linking every possible dyad in the agreement. Technical alliances formed by dyad ranged from 0 to 5, with a mean of 0.020.

*Director interlocks:* Two companies are interlocked when at least one member of a firm’s board sits as a director on the board of the other firm (Mizruchi, 1996, p. 273). All publicly traded companies in the United States are required to have a board consisting of at least three persons. Usually, outside directors are distinguished from inside directors. Outside directors are mainly affiliated with an organization other than the focal firm, whereas inside directors belong to the same firm and usually hold a position in the top executive team. Interlocks can be established by both inside and outside directors, as well as a member of the senior executive team (i.e.,

executives listed in the proxy statement). If an executive of firm A, who usually also holds a directorship position at that firm, serves as a director at firm B, a director–officer interlock between firm A and B is established. Director–officer ties can be distinguished from neutral interlocks, where an individual serves on the board of two companies as an outside director.

Neutral interlocks between two companies were coded 1 when the same name appeared on two corporate board listings within a given year and the boundary spanner was an outside director in both firms. Director–officer interlocks were coded 1 when the same name appeared on two corporate board listings within a given year and the boundary spanner held an executive officer position in one of the firms.

*CTO participation:* Joint CTO participation is the number of CTO meetings in a given year in which both of the firms in the dyad participated. This variable ranges from a minimum of 0 to a maximum of 46, while the average is 0.80. Because the number of CTO meetings increased yearly, we control for the yearly CTO meeting count in all analyses.

*Previous dyadic technical alliances:* We include the number of technical alliances formed by the dyad during the previous three years, as well as its square, to control for the inverted U-shaped relationship between previous and subsequent relationships (Gulati, 1995).

### Controls

The variable *patent differential* identifies each firm’s explicit strength in cellular technology with yearly counts of all patents in the cellular classes 371, 375, 333, 370, 379, 455, 380 and 273 of the US patent system. For each dyad, we both summed and differenced patents of both firms and then logged this figure because the variable was highly skewed. Since these two measures were highly correlated ( $r = 0.072$ ), we ran analyses with each form of the patent variable. Results were comparable across all other variables, but the difference variable achieves significance in more of our models than the sum does. Hence, we report the results for the difference rather than the sum.

We also control for whether or not the two firms occupy similar positions in the overall network with the variable *centrality ratio*. This variable

compares the network position of each firm in the joint CTO participation network as represented by its ability to control information flow. Theoretically, Gulati and Gargiulo (1999) have argued that similar network position connotes similar status, which may lead firms to be drawn to each other as partners that reaffirm status levels. Operationally, this variable can control for unobserved mechanisms that might lead both firms to achieve similar network position due to their patterns of CTO participation. For the measure, we calculated the betweenness centrality of each firm in the CTO participation network for the given year. This measure indicates the extent to which a given firm is a necessary node in the paths between all dyads in the network (Freeman, 1979). In other words, it suggests the power of the firm to control information flows in the network, and has been used as a common measure of influence in network studies. For each dyad in each year, we divided the centrality of the lower-centrality firm by the centrality of the higher-centrality firm to obtain the centrality ratio. This control variable approaches its maximum of 1 for dyads in which both firms have similar structural positions in the CTO network, so we would expect the variable to have a positive effect if the Gulati and Gargiulo argument is correct. If both firms had a centrality of zero, we set the measure to zero.<sup>3</sup>

The binary variable, *dyadtype*, was coded 1 if both firms in the dyad were of the same type (service providers or manufacturers), indicating whether the alliance type is horizontal or vertical. Since alliance formation is positively associated with *size* of the firm (Stuart, 1998), the logged sum of each firm's sales is included as a control variable. Each firm's *total number of alliances* formed with any cellular firm during the previous year controls for firm-level propensities toward alliance formation.<sup>4</sup> As mentioned earlier, we also control for the *number of CTO meetings* held during the year. The number of CTO meetings serves as a substitute for yearly dummies. Whenever we do not include the number of CTO meetings as a control, we included year controls for the years 1991 to 1994 (Year 1–Year 4). The year 1995 serves as an omitted category.

Table 2(a)–(c) lists all the variables, their definitions and posited effects. Table 3 displays descriptive statistics and correlations.

## ANALYSES

We used the firm dyad as our level of analysis. Although we derived our sample at the firm level, every dyadic relation among those firms is a candidate case for our analyses. Due to entries and exits of firms during the study period, our longitudinal data set is unbalanced, resulting in 14 059 dyads for predicting alliance formation.

To explore the effect of board interlocks and joint CTO participation on subsequent alliance formation, we regress alliance formation in a given year (during 1992–1996) on all independent and control variables for the previous year (1991–1995). Since our dependent variable is a count, Poisson methods are appropriate. Given the high variance relative to the mean, however, negative binomial regression is indicated (Hausman *et al.*, 1984). Since dyads may differ in their propensity to form alliances in ways that are unaccounted for by our explanatory variables, we employ a random effects model (Stuart, 1998; Gulati and Gargiulo, 1999).

Several models of independent variables were regressed on the dependent variable of alliance formation (see Table 4). *Model 1* includes all the control variables that account for the effect of joint CTO participation and director interlock ties on alliance formation. *Model 2* shows the effect of all director interlock ties on alliance formation. The broad category director ties is split up into the two subcategories of neutral and director–officer ties in *Model 3* to compare their respective influences on alliance formation. *Model 4* tests the relation between joint CTO participation and alliance formation by adding the linear and squared effects of joint CTO participation. Director–officer interlocks and joint CTO participation variables are included in *Model 5* simultaneously to compare the strength of the effects. Finally, the interaction between joint CTO participation and director interlock ties is included in *Model 6*.

To explore the potential coevolution of alliance formation, director interlock ties and joint CTO participation, we regress director interlocks on a set of our lagged independent variables, including both the three-year window of previous alliance formation and the joint CTO participation (see Table 5). Since the variance of the dependent variable was substantially lower for this measure than for alliance formation (the maximum number of interlocks is two), we employed probit methods for our analysis. Analogously, we represent joint

**Table 2. List of Variables and Predictions for (a) Table 4, (b) Table 5 and (c) Table 6**

| Variable name                                      | Definition <sup>a</sup>                                                                             | Hypothesis | Predicted sign  |
|----------------------------------------------------|-----------------------------------------------------------------------------------------------------|------------|-----------------|
| (a)                                                |                                                                                                     |            |                 |
| Alliances                                          | Number of all technical alliances formed by dyad                                                    |            | Dep. Var.       |
| Total director interlocks                          | All interlocks linking two firms in the sample                                                      | 1a         | +               |
| Director–officer interlocks                        | Number of interlocks where the boundary spanner has an executive position in one of the firms       | 1b         | +               |
| Joint CTO participation                            | Number of CTO meetings in which both firms in the dyad participated                                 | 2          | +               |
| (Joint CTO participation) <sup>2</sup>             | Number of CTO meetings in which both firms in the dyad participated                                 | 2          | –               |
| Director–officer interlock*joint CTO participation | Interaction term                                                                                    | 3          | +               |
| Neutral director interlocks                        | Number of interlocks where boundary spanner is an outside director in both firms                    |            | NP <sup>b</sup> |
| Dyadtype                                           | Dummy valued 1 if both firms in the dyad are either service providers or equipment manufacturers    |            | NP              |
| Previous dyadic technical alliances                | Number of technical alliances formed by dyad over three-year window ( $t-1$ through $t-3$ )         |            | NP              |
| (Previous dyadic technical alliances) <sup>2</sup> | Number of technical alliances formed by dyad over three-year window ( $t-1$ through $t-3$ ) squared |            | NP              |
| Patent differential                                | Absolute difference of the two firms' patents, logged                                               |            | NP              |
| Centrality ratio                                   | CTO network betweenness centrality ratio: lower firm's value divided by higher firm's value         |            | NP              |
| Size                                               | Sum of the two firms' sales, logged                                                                 |            | NP              |
| Firm alliances                                     | Total number of alliances formed by the focal firm with any other cellular firm                     |            | NP              |
| Year 1                                             | Fixed effect for 1991                                                                               |            | NP              |
| Year 2                                             | Fixed effect for 1992                                                                               |            | NP              |
| Year 3                                             | Fixed effect for 1993                                                                               |            | NP              |
| Year 4                                             | Fixed effect for 1994 <sup>c</sup>                                                                  |            | NP              |
| (b)                                                |                                                                                                     |            |                 |
| Director interlock                                 | Dummy indicating the formation of a director interlock                                              |            | Dep. Var.       |
| Previous dyadic alliances                          | Number of alliances formed by dyad over three-year window ( $t-1$ through $t-3$ )                   | 4a         | +               |
| Joint CTO participation                            | Number of CTO meetings in which both firms in the dyad participated                                 | 4c         | +               |
| Total director interlocks                          | All interlocks linking two firms in the sample                                                      |            | NP              |
| Patent differential                                | Absolute difference of the two firms' patents, logged                                               |            | NP              |
| Centrality ratio                                   | CTO network betweenness centrality ratio: lower firm's value divided by higher firm's value         |            | NP              |
| Dyadtype                                           | Dummy valued 1 if both firms in the dyad are either service providers or equipment manufacturers    |            | NP              |
| Size                                               | Sum of the two firms' sales, logged                                                                 |            | NP              |
| (c)                                                |                                                                                                     |            |                 |
| Joint CTO participation                            | Dummy indicating that both firms in the dyad jointly participated in a CTO meeting                  |            | Dep. Var.       |
| Previous dyadic alliances                          | Number of alliances formed by dyad over three-year window ( $t-1$ through $t-3$ )                   | 4b         | +               |
| Total director interlocks                          | All interlocks linking two firms in the sample                                                      | 4d         | +               |
| Joint CTO participation                            | Number of CTO meetings in which both firms in the dyad participated                                 |            | NP              |
| Patent differential                                | Absolute difference of the two firms' patents, logged                                               |            | NP              |
| Centrality ratio                                   | CTO network betweenness centrality ratio: lower firm's value divided by higher firm's value         |            | NP              |
| Dyadtype                                           | Dummy valued 1 if both firms in the dyad are either service providers or equipment manufacturers    |            | NP              |
| Size                                               | Sum of the two firms' sales, logged                                                                 |            | NP              |

<sup>a</sup> All independent variables calculated on  $t-1$  unless otherwise specified.<sup>b</sup> NP, no prediction.<sup>c</sup> 1995 is the omitted category.

Table 3. Descriptive Statistics and Correlations for Dyads ( $N=14\,059$ )

| Variable                                              | Mean   | SD    | Min   | Max  | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14    | 15   | 16    | 17    | 18    |
|-------------------------------------------------------|--------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|
| 1. Technical alliances                                | 0.020  | 0.18  | 0     | 5    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 2. Total director interlocks                          | 0.003  | 0.065 | 0     | 3    | 0.05  |       |       |       |       |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 3. Neutral interlocks                                 | 0.002  | 0.047 | 0     | 2    | 0.03  | 0.75  |       |       |       |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 4. Director-officer interlocks                        | 0.001  | 0.033 | 0     | 2    | 0.06  | 0.50  | -0.00 |       |       |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 5. Joint CTO participation                            | 0.80   | 3.07  | 0     | 46   | 0.05  | 0.03  | 0.03  | -0.00 |       |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 6. (Joint CTO participation) <sup>2</sup>             | 10.05  | 71.70 | 0     | 2116 | 0.03  | 0.03  | 0.02  | -0.00 | 0.89  |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 7. Director-officer interlock                         | 0.0009 | 0.078 | 0     | 9    | 0.09  | 0.14  | -0.00 | 0.28  | 0.02  | 0.01  |       |       |       |       |       |       |       |       |      |       |       |       |
| *joint CTO participation                              |        |       |       |      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |       |       |       |
| 8. Previous dyadic technical alliances                | 0.55   | 0.36  | 0     | 9    | 0.32  | 0.05  | 0.04  | 0.03  | 0.08  | 0.07  | 0.07  |       |       |       |       |       |       |       |      |       |       |       |
| 9. (Previous dyadic technical alliances) <sup>2</sup> | 0.13   | 1.80  | 0     | 81   | 0.24  | 0.04  | 0.04  | 0.01  | 0.02  | 0.01  | 0.04  | 0.85  |       |       |       |       |       |       |      |       |       |       |
| 10. Patent differential                               | 0.51   | 0.55  | 0     | 2.2  | 0.05  | 0.01  | -0.01 | 0.01  | 0.29  | 0.21  | 0.02  | 0.12  | 0.06  |       |       |       |       |       |      |       |       |       |
| 11. Centrality ratio                                  | 0.85   | 0.21  | 0     | 0.99 | 0.05  | 0.03  | 0.02  | 0.01  | 0.50  | 0.33  | 0.02  | 0.06  | 0.02  | 0.13  |       |       |       |       |      |       |       |       |
| 12. Dyadtype                                          | 0.51   | 0.50  | 0     | 1    | 0.05  | 0.01  | 0.01  | 0.00  | -0.01 | -0.01 | 0.01  | 0.06  | 0.05  | 0.03  | -0.01 |       |       |       |      |       |       |       |
| 13. Size                                              | 8.63   | 2.00  | 0.028 | 12.0 | 0.11  | 0.02  | 0.02  | 0.01  | 0.20  | 0.12  | 0.01  | 0.15  | 0.08  | 0.42  | 0.20  | -0.01 |       |       |      |       |       |       |
| 14. Alliances formed by firm 1                        | 7.74   | 15.02 | 0     | 76   | 0.17  | 0.04  | 0.04  | 0.01  | 0.12  | 0.11  | -0.00 | 0.24  | 0.14  | 0.22  | 0.07  | 0.04  | 0.37  |       |      |       |       |       |
| 15. Alliances formed by firm 2                        | 8.12   | 13.82 | 0     | 76   | 0.13  | 0.02  | 0.02  | 0.01  | 0.07  | 0.06  | 0.02  | 0.19  | 0.13  | 0.23  | 0.09  | 0.03  | 0.35  | -0.01 |      |       |       |       |
| 16. Year 1                                            | 0.17   | 0.38  | 0     | 1    | 0.02  | 0.00  | 0.00  | 0.01  | 0.01  | -0.01 | 0.02  | -0.01 | -0.01 | -0.10 | 0.07  | -0.00 | -0.01 | -0.03 | 0.01 |       |       |       |
| 17. Year 2                                            | 0.19   | 0.39  | 0     | 1    | 0.03  | -0.00 | -0.00 | -0.01 | -0.00 | -0.00 | -0.00 | -0.01 | 0.01  | -0.01 | -0.02 | -0.00 | 0.01  | -0.01 | 0.00 | -0.23 |       |       |
| 18. Year 3                                            | 0.22   | 0.41  | 0     | 1    | -0.02 | 0.00  | 0.00  | -0.00 | -0.02 | 0.02  | -0.01 | 0.02  | 0.01  | 0.06  | -0.00 | -0.00 | -0.00 | 0.06  | 0.01 | -0.25 | -0.26 |       |
| 19. Year 4                                            | 0.25   | 0.44  | 0     | 1    | -0.03 | -0.01 | 0.00  | 0.01  | -0.00 | 0.02  | -0.00 | 0.01  | 0.00  | 0.13  | -0.07 | 0.01  | -0.01 | -0.00 | 0.04 | -0.27 | -0.28 | -0.31 |

**Table 4. Random-Effects Negative Binomial Estimates of Dyad-level Technical Alliance Formation ( $N = 14,059$ )**

| Independent variable                               | 1         | 2         | 3         | 4         | 5         | 6         |
|----------------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Total director interlocks                          |           | 1.04***   |           |           |           |           |
| Director-officer interlocks                        |           |           | 2.03***   |           | 2.01***   | 2.01***   |
| Neutral interlocks                                 |           |           | 0.458     |           |           |           |
| Joint CTO participation                            |           |           |           | 0.094**   | 0.091**   | 0.091**   |
| (Joint CTO participation) <sup>2</sup>             |           |           |           | -0.003*   | -0.003*   | -0.003*   |
| Joint CTO participation                            |           |           |           |           |           | 0.001     |
| *director-officer interlock                        |           |           |           |           |           |           |
| Previous dyadic technical alliances                | 0.643***  | 0.643***  | 0.608***  | 0.630***  | 0.583***  | 0.584***  |
| (Previous dyadic technical alliances) <sup>2</sup> | -0.068*** | -0.072*** | -0.065*** | -0.064*** | -0.060*** | -0.060*** |
| Patent differential                                | -0.216*   | -0.202    | -0.211*   | -0.317**  | -0.313**  | -0.313**  |
| Centrality ratio                                   | 0.692**   | 0.667***  | 0.704***  | 0.318     | 0.338     | 0.338     |
| Dyadtype                                           | 0.587***  | 0.583***  | 0.597***  | 0.591***  | 0.583***  | 0.584***  |
| Size                                               | 0.555***  | 0.565***  | 0.558***  | 0.555***  | 0.556***  | 0.556***  |
| Alliances formed by firm 1                         | 0.031***  | 0.031***  | 0.032***  | 0.031***  | 0.029***  | 0.032***  |
| Alliances formed by firm 2                         | 0.028***  | 0.027***  | 0.028***  | 0.028***  | 0.026***  | 0.029***  |
| Year 1                                             | 0.396*    | 0.394*    | 0.375*    | 0.386*    | 0.359*    | 0.359*    |
| Year 2                                             | 0.485**   | 0.496**   | 0.491**   | 0.512**   | 0.513**   | 0.514**   |
| Year 3                                             | -0.728*** | -0.769*** | -0.763*** | -0.697*** | -0.718*** | -0.718*** |
| Year 4                                             | -0.638*** | -0.683*** | -0.698*** | -0.622*** | -0.669*** | -0.669*** |
| Constant                                           | -8.81***  | -8.84***  | -8.73***  | -8.89***  | -8.76***  | -8.76***  |
| Log likelihood                                     | -990.62   | -987.28   | -984.31   | -987.57   | -981.80   | -981.80   |

\* $p < 0.10$ ; \*\* $p < 0.05$ ; \*\*\* $p < 0.01$ .

**Table 5. Probit Estimates of Director Interlocks ( $N = 14,059$ )**

| Independent variable <sup>a</sup>  |          |
|------------------------------------|----------|
| Previous dyadic alliances          | 0.235*** |
| Joint CTO participation            | 0.032**  |
| Previous total director interlocks | 2.146*** |
| Patent differential                | -0.048   |
| Centrality ratio                   | -0.399   |
| Dyadtype                           | -0.163   |
| Size                               | 0.061    |
| Constant                           | -3.33*** |
| Log likelihood                     | -220.01  |

<sup>a</sup>Dependent variable is a binary indicator of director interlock formation.

\* $p < 0.10$ ; \*\* $p < 0.05$ ; \*\*\* $p < 0.01$ .

**Table 6. Probit Estimates of Joint CTO Participation ( $N = 14,059$ )**

| Independent variable <sup>a</sup> |          |
|-----------------------------------|----------|
| Previous dyadic alliances         | -0.024   |
| Total director interlocks         | -0.091   |
| Previous joint CTO participation  | 0.081*** |
| Patent differential               | 0.118*** |
| Centrality ratio                  | 1.198*** |
| Dyadtype                          | -0.037   |
| Size                              | 0.140*** |
| Constant                          | -2.90*** |
| Log likelihood                    | -3905.53 |

<sup>a</sup>Dependent variable is a binary indicator of joint CTO participation.

\* $p < 0.10$ ; \*\* $p < 0.05$ ; \*\*\* $p < 0.01$ .

CTO participation as a dummy variable and regress it on lagged independent variables which include the three-year window of previous alliance formation and the total director interlocks (see Table 6).

## RESULTS

Hypotheses 1a and 1b are supported (see *Models 2* and *3*). Total director interlocks have a significant effect on alliance formation (1a), but the crucial

predictor of alliance formation is director-officer interlocks (1b). While the variable total director interlocks is a significant positive predictor of alliance formation, splitting this category into neutral interlocks and director-officer interlocks reveals that the effect of interlocks on alliance formation is driven by director-officer interlocks. Neutral interlocks are not significant.<sup>5</sup> These results suggest that the insight of executive boundary spanners into the operational business facilitates recognition of contractual opportunities.

*Model 4* demonstrates that joint CTO participation obtains a significant positive first-order effect, while the squared term of joint CTO participation obtains a significant negative effect. These results support our Hypothesis 2 that joint CTO participation increases the likelihood of subsequent alliance formation at a diminishing rate. An increase in the number of CTO meetings visited by the same pair of firms increases their propensity to form an alliance with each other. However, the more meetings are co-attended, the less is the effect of each additional co-attended meeting on the propensity of alliance formation between those two firms.

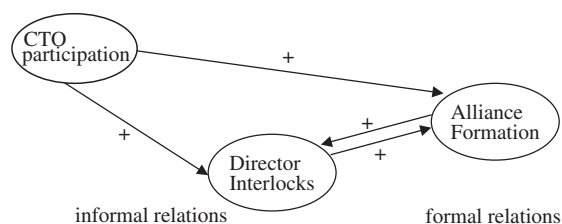
*Model 5* reinforces our proposition that director–officer interlocks and joint CTO participation are both important informal ‘pre-alliance’ venues. The significance, the magnitude and the direction of the CTO coefficient and the director–officer coefficient does not change when the CTO variable and the director–officer interlock variable are put into the model at the same time. *Model 6* includes the interaction between joint CTO participation and director interlock tie, which is covered in Hypothesis 3. The interaction is not significant and therefore Hypothesis 3 is not supported.<sup>6</sup> As a consequence, the two variables seem to be neither substitutional nor complementary: as suggested in *Model 5*, each variable maintains its own independent effect.

Most control variables are significant in the expected directions. The year effects demonstrate dramatic fluctuations across the study period, which reflects the introduction of new technological standards at this time. Centrality ratio loses significance when the fully specified curvilinear effect of joint CTO participation is included in the model. Apparently, measures such as centrality ratio that incorporate larger structural characteristics are not adding additional explanatory power over the dyadic properties captured in joint CTO participation alone, and this is likely due to our context, where highly technical information can be discussed in dyads but is unlikely to be transmitted effectively across longer network paths between multiple partners. Finally, the patent differential is negatively related to alliance formation: the greater the difference in the patent outputs of the two firms, the less likely they are to form an alliance. In other words, similarity in patent output among the two firms increases the likelihood of alliance formation.

Table 5 employs a binary dependent variable indicating the existence of a dyadic director interlock (either director–director or director–officer). Previous dyadic alliances is a strong predictor of subsequent director interlock formation and has a positive impact, even when controlling for prior director interlocks for the prior year, supporting Hypothesis 4a. Likewise, joint CTO participation also has a significant positive effect on the formation of a subsequent director interlock, supporting Hypothesis 4c.

The dependent variable in Table 6 is a binary variable indicating joint participation in CTO activities. Clearly, lagged joint CTO participation is a significant predictor of current joint CTO participation, suggesting that changes in participation profiles are not dramatic on a year-to-year basis. With this effect controlled, neither previous dyadic alliance formation nor director interlock obtains a significant effect on joint CTO participation. As a result, Hypothesis 4b, which states that prior alliance formation facilitates joint CTO participation, is not supported. Likewise, Hypothesis 4d, stating that director interlocks increase the likelihood of joint CTO participation, is not supported. While patent differentials are not related to director interlocks, they are related to joint CTO participation. The positive sign on patent differential suggests that the greater the differential in patent counts, the more likely the two firms to jointly participate in CTO activity.<sup>7</sup>

These results have several implications for our assumptions on dynamics between informal and formal interorganizational relations. Our findings are summarized in Figure 3. The regressions of Table 4 show that informal interorganizational relations (director interlocks, joint CTO participation) facilitate formal interorganizational relations (strategic alliances). However, while prior alliance formation does facilitate the formation of director



**Figure 3.** Observed co-evolution of networks.

interlocks within a dyad (Table 5), prior alliance formation does not facilitate subsequent joint CTO participation (Table 6). These results indicate a reinforcing coevolution between alliance formation and director interlocks. In contrast, joint CTO participation causally precedes alliance formation.

The results also suggest an asymmetric relationship between the two informal interorganizational venues, director interlock and joint CTO participation. Prior joint CTO participation facilitates the formation of director interlocks (Table 5). This may well be because alliance formation mediates this relationship. However, prior director interlocks do not increase the likelihood of joint CTO participation, as suggested in Hypothesis 4d (Table 6). Joint CTO participation influences both alliance formation and director interlock formation, but is not endogenously influenced by them.

In summary, these results suggest that joint CTO participation has a fundamentally different relation to strategic alliance formation than director interlocks. While director interlocks seem to co-evolve with alliance formation, joint CTO participation is a more detached 'pre-alliance' arena. Joint CTO participation has a strong effect on subsequent alliance formation and is not influenced by either prior existing director interlocks or previous alliance formations. As a result, the CTO venue seems to provide a venue for non-established firms to make their way into relationships among firms already established in the alliance network.

## DISCUSSION

This paper highlights the multiplicity of interorganizational relations and their effects on each other. In our analysis we focus on one type of formal interorganizational relation (alliances) and two types of informal ones (joint CTO participation and director interlocks). In terms of their visibility and data availability, alliances can be compared to the most visible tip of an iceberg above the water surface that rests upon a large body of ice (informal relations) hidden below the surface. Formal interorganizational relations like alliances are closely interwoven with less obvious, more informal relations like director interlocks and joint CTO participation.

Our simultaneous examination of three network venues—CTOs, top-level interlocks and alliances—suggests the multiplex nature of knowledge flows in technological communities. Any discussion of 'knowledge networks' should aggregate a host of ties, both formal and informal, that facilitate flows of knowledge among firms. Our examination of three such ties suggests that while there may be noticeable correlations among the varied types of ties, systematic study enables the identification of causal precedence among certain types, which raises the possibility that knowledge networks evolve through stages (e.g., Powell *et al.*, 2002).

Our analyses suggested that the informal venues—CTOs and interlocks—may serve as contexts that enable the identification of alliance opportunities and hence the formation of formal ties. One important difference between the two venues is that the interlock–alliance relationship also demonstrated reverse causality; that is, alliance formations also predicted subsequent interlocks. In contrast, no endogeneity between joint CTO participation and alliance formation was found—CTOs provide, unambiguously, a 'pre-alliance' context. One explanation for this contrast among the two informal venues may be that alliances raise resource dependence issues that are symbolized by the appointment of a director who also has links to the alliance partner. In contrast, since joint CTO participation represents common technical interests, alliances are as likely to lead to complementary specialization (and therefore technological divergence and less joint CTO participation) as to technological convergence (and therefore more joint CTO participation) (Mowery *et al.*, 1996). Hence, no additional CTO linkages were identified subsequent to alliances.

Another important finding in this research was the distinction of effects across different types of top-level interlocks. We showed that the effect of interlocks on subsequent alliance formation was contingent on the interlocking person being an officer in one of the firms. In other words, 'neutral' interlocks (where the interlocking person is an outside director at both firms) did not predict subsequent alliance formation. This finding adds an important dimension to most research on the effects of interlocking directorates on information exchange and subsequent practices. Interlock research does not typically include (non-director)

officers even though an executive team member serving on another board can provide the same mechanisms for information flow between the two firms as an actual director interlock. Given our interest in technical alliance formation, we expect that an interlocking person would require some knowledge of the relevant technologies for the business, and it is unlikely that a person who serves as outside director for both firms would have this knowledge. It is more likely that a person with operational responsibility at one of the firms would have this knowledge, and perhaps even more likely that mid-level people participating in CTOs would have the ability to identify opportunities for collaborative work.

Of course, the generalizability of our research may be limited. The cellular industry is a fertile area to study the effects of multiple network ties due to several of its features: the systemic nature of the technology requires standards and therefore cooperation; intellectual property issues are present but are mitigated through technical committee agreements and licensing arrangements; regulation is moderately high; and the service market is increasingly concentrated while the equipment market is more fragmented. Future research must examine how factors such as varied appropriability regimes, technological complexity, regulatory presence, and market concentration may attenuate or increase the dynamics we have observed.

In conclusion, this paper has demonstrated how informal network contexts shape (and are sometimes shaped by) formal alliance networks. In contrast to the prevalent perspective that alliance networks are self-reproducing and endogenous, we suggested that informal networks provide contexts where managerial agency can shape alliance outcomes. In demonstrating that the effects of informal networks may depend on the managerial level at which the links are formed, we added richness to the typical conception of interorganizational networks constituted by a single tie. Future research must continue to explore the multiplicity of formal and informal relations that constitute the context for strategic decisions by managers.

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### NOTES

1. In general, the selection of a director from the same industry is rather rare. Most studies of the effects of director interlocks focus on Fortune 500 firms and therefore capture predominantly inter-industry interlocks.
2. This may have introduced some bias toward larger firms. Nonetheless, since alliance studies have demonstrated the critical effect of size on alliance formation, we are obligated to control for it in our analyses. This insures that effects of informal relationships on alliance formation are not caused by a spurious correlation with size, since larger firms participate more in CTOs and have more interlocks. With our sample restricted in this way, we do not have full alliance data for the non-public firms, and they are not as effectively covered in SDC. Our data about the total set of 174 firms do suggest that smaller firms are slightly less active in the CTO venue, and we would expect that they are also forming fewer alliances.
3. Alternative constructions of relative centrality, such as sums and differences, provided the same results.
4. Following Gulati and Gargiulo (1999), these variables also serve as pseudo-proxies for firm fixed effects, as fixed effects over short time periods can lead to biased estimates.
5. These results remained robust when we regressed alliance formation on accumulated interlocks of a given firm dyad over the study period. This accounts for a potential effect of interlocks beyond the single-year lag.
6. We also tried to discern an effect from this interaction when the squared term of joint CTO participation was not included in the model (to avoid any possible multicollinearity), but still no effect emerged. This was also the case when we transformed both counts into binary variables and calculated their interaction.
7. While this effect may seem counterintuitive, it represents the fact that the higher-patenting firms tend to participate in most CTO meetings. Indeed, additional runs with patent sum rather than patent differential yielded significant positive results for the effect of patent sum on alliance formation.

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