Network Effects in the Governance of Strategic Alliances

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We argue that the stock of prior alliances between participants in the biotechnology sector forms a network that serves as a governance mechanism in interfirm transactions. To test how this network substitutes for other governance mechanisms, we examine how equity participation and pledged funding in strategic alliances vary with two features of the way alliance participants are positioned in the network of past deals: proximity, or how close two firms are to one another in the network; and centrality, or how deeply a firm is embedded in the network. As centrality and proximity increase, equity participation (measured by size and propensity) diminishes, whereas pledged funding increases.

1. Introduction

Strategic alliances and joint ventures are long-term collaborations between legally distinct organizations. Although once relatively rare, they are now a common mechanism for organizing corporate activity, especially in high-tech, R & D–intensive settings. Because incentive problems and conflicts of interest are endemic to these collaborations, alliance contracts provide an ideal lens through which to study empirical solutions to moral hazard and holdup problems.

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Past empirical evidence has demonstrated the importance of equity ownership in reducing incentive problems in interfirm transactions. In this article, we focus on a different mechanism. We argue that the stock of past alliances gives rise to a communication network that affects the allocation of control in strategic alliance agreements by allowing long-term reputational concerns to affect the terms of specific contracts. We then demonstrate this by showing that the use of equity in alliance agreements—an alternative mechanism for allocating control—is affected by the positions of the contracting parties in the broader alliance network.

A network arises when individuals in one firm do business with individuals in another firm, thereby establishing a link that lowers the cost (or raises the accuracy) of subsequent communication. The communication links in the network allow partners to convey privileged information about one another to other network members. This, in turn, potentially affects a counterparty's reputation among future business partners. However, because the information conveyed through network ties is not necessarily available to all network members, the effectiveness of the network as a tool for selecting and sanctioning alliance participants should vary according to the way firms are positioned in it (Raub and Weesie 1990).

In a sample of over 3800 alliance transactions between pharmaceutical firms and biotechnology research firms, we show that firms take more frequent, and larger, equity positions in collaborations with partners who occupy peripheral positions in the network of past alliances. The same is true in transactions with partners who are more distant from them in the network. Thus, better networked firms rely less on explicit control mechanisms such as equity ownership and more on implicit, network-based control, all else equal.

The size of these effects is economically important: for example, a 1-standard deviation (SD) increase in the biotechnology firm's centrality lowers the probability of equity by about 10%. The probability of equity falls by about 2% for a 1-SD increase in the proximity of the two firms. Given that about 20% of all alliances in our sample involve equity, these effects are large.

An alternative explanation for these findings is that better-networked firms are simply higher quality firms. To control for this alternative, we track firms' patent histories. We also include a firm's prior history of alliance participation to control for unobserved differences in the propensity to use alliances. Our findings are robust to these alternative explanations, as well as others, including the fact that network positioning affects the probability of an alliance, in addition to its control structure.

We also study how network positioning influences the well-documented tendency for more complex activities to involve greater equity participation. A key prediction of transaction cost economics is that when contracts are incomplete, increasing the potential for ex post holdup should increase the incidence of vertical integration (Williamson 1975). A large literature has offered empirical confirmation of this prediction in a variety of contexts. Testing this proposition in the context of alliances, Pisano (1989) and Oxley (1997) have demonstrated that in R & D–intensive transactions, strategic alliances are more likely to involve equity participation. Although this result holds in our sample, it hinges on firms' ability to access the network. The tendency to use equity in early-stage R & D alliances diminishes with the alliance participants' increased access to the network.

Finally, the network effects we demonstrate are more pronounced among privately held firms. Because these are the firms about which there is less publicly verifiable information, the potential role for the network to affect transactional governance is greatest in deals involving private firms.

These findings contribute to a number of distinct literatures exploring the determinants of control in strategic alliance agreements, as well as other contracting situations. The results extend the existing literature on strategic alliances by illustrating that the determinants of the allocation of control extend beyond the bilateral transaction history of the firms in question. This supports theoretical arguments by Baker et al. (2004) and others who focus on relational mechanisms in contract enforcement. Our findings allow us to conclude that opportunism is mitigated by a counterparty's reputation among potential future contracting partners, not just through its reputation with preexisting partners. Thus, the links that two transaction partners have to other firms outside the alliance influence the allocation of control in their alliance by creating opportunities to affect each firm's reputation capital.

In addition, our work complements a growing empirical literature that examines the interaction of contract provisions with other mechanisms for guarding against moral hazard. Arruñada et al. (2001), for example, study the allocation of decision-making rights in automobile manufacturer/dealer contracts and find that more rights are allocated to manufacturers when their opportunism can be controlled by their reputation. Similarly, Corts and Singh (2004) show that repeated interaction substitutes for contract specificity in offshore oil-drilling contracts. We obtain similar results using measures that specifically capture variation in the ability to influence a counterparty's reputation through noncontractual means.

Finally, our results complement the literature that examines social, or community, enforcement mechanisms (see Ellickson [1991] or Greif [1993]). We show that the alliance network acts as a social institution that aids in contract enforcement. This generalizes reputation arguments to contexts in which costly information transmission or community enforcement are salient. Our results suggest that the alliance network plays the same role as the court in Johnson et al. (2002) in fostering the trust necessary to forge new interactions between firms in this sector.

The remainder of the article is organized as follows. Section 2 links equity participation and network variables to incentive problems in strategic alliances. This describes our network measures and develops predictions concerning how the network substitutes for other forms of governance. Section 3 provides the mathematical details for the empirical measures of network positioning (centrality and proximity) that allow us to test these predictions. Section 4 describes our sample while Section 5 discusses our estimation strategy. Section 6 presents our findings, and Section 7 concludes.

2. The Analytical Framework

2.1 Strategic Alliances in Biotechnology

As Lerner and Merges (1998), National Science Board (2000), Robinson (2001), and others have shown, interfirm strategic alliances have emerged as a common method of organizing corporate R & D activity. According to the National Science Foundation (1997), the dollar value of collaborative agreements with outside organizations nearly doubled between 1991 and 1997. In fact, this rate of growth significantly understates the increase in the biotechnology sector, where over 5500 alliances between dedicated biotechnology firms, pharmaceutical firms, and universities have been consummated since 1976.

The alliances we examine are collaborative agreements in which a biotechnology research firm (deemed the *target*) acts as an agent either to a pharmaceutical firm or, less frequently, to a larger biotech firm (in either case deemed the *client*). The collaborations in our sample describe different types of business activities, but a typical deal entails the target performing upstream R & D, which becomes an input to a final drug product that the client then manufactures and distributes in most geographic markets. This client's sponsorship often takes the form of up-front payments, combined with staged, milestone-based funding. Sometimes the client takes an equity stake in the target firm. Revenues from the ultimate sale of the drug are sometimes shared with the target through a licensing agreement.

As many authors have noted, these agreements are fraught with moral hazard, asymmetric information, and other contracting problems. First, the negotiating parties in these deals typically have asymmetric information about project quality; clients often know less about the subject of a possible alliance than do targets, especially in early-stage research projects that are to be conducted by the target on its premises. Second, these deals routinely grant targets control over clients' capital. Third, collaborations in biotechnology frequently are created to develop new technologies, which is an inherently uncertain and unpredictable endeavor. At the time the contract must be signed, it can be difficult to specify all the significant features of the technology to be created, and it is similarly difficult to delineate all the commercial and regulatory contingencies that might arise in the implementation of the agreement. Moreover, these agreements explicitly deal with issues that seem difficult to verify and costly to enforce. For example, it is often necessary for biotech alliances to specify the quantities of scientific labor that targets must devote to a project, but it is common in such situations for the contracts to be silent regarding how labor quality is determined or verified (Robinson and Stuart forthcoming).

2.2 Equity Participation and Control in Strategic Alliances

Following a number of studies, we use the presence and amount of equity ownership assumed by the client as our measure of the client's control rights in the strategic alliance. The relation between equity and control rights is empirically supported in the context of strategic alliances in the work of Pisano (1989), Allen and Phillips (2000), Boone (2001), and others. Allen and Phillips (2000) report that holders of minority equity stakes are often granted a seat on the target's board. Likewise, Boone (2001) shows that firms which spin-off internal divisions are most likely to retain a partial equity stake in the spin off when the two entities share a product market relationship. These findings suggest that one of the benefits of equity ownership is that the equity holder can influence the actions of the target, preventing it from taking actions that come at the equity holder's expense. Similarly, Pisano (1989) shows that strategic collaborations involving R & D are more likely than other types of alliances to include minority equity participation. Due to the inherent unpredictability of R & D alliances, clients appear to rely more heavily on equity-based control in these deals to protect themselves against holdup problems arising from incomplete contracts and other transaction-related risks.

The optimal equity stake presumably balances the benefits of equity participation, in terms of monitoring, the allocation of control, or transaction costs minimization, against the costs of the equity stake. Two main costs of equity participation are diluted target incentives to make relationship-specific investments (Aghion and Tirole 1994; Rajan and Zingales 1998) and the inefficiencies that arise from placing control in the hands of less informed actors (Aghion and Tirole 1994). In addition, Wu (2001) reports that private equity placements with peer firms often occur at a premium, unlike private equity placements to individuals, which take place at discounts. This suggests that, at least in some deals, the client must pay a price for the control it obtains.

Prior work has thus examined the use of equity to address incentive conflicts in alliance transactions. Here, we focus on how the structure of the interfirm communication network mitigates incentive conflicts among alliance partners and therefore provides a substitute to the use of equity in alliance transactions. We assume that the details of an agent's conduct in its past alliances cannot be observed publicly. Instead, information about past behavior is transmitted across private communication links. This assumption is also implicit in Greif's (1989, 1991) study of medieval trading networks, in which traders separated by vast geographic distances deter opportunism by spreading news of malfeasance to other trading partners (see also Raub and Weesie 1990; Gulati 1995; Uzzi 1996). In each of these articles, information about reputations is costly to transmit and variably held.

In biotech strategic alliances, the assumption that information about a counterparty's business-related actions is not publicly available is justifiable for a number of reasons. High unconditional failure rates in the drug development process make it difficult to attribute failure in product development efforts to a lack of technical capability or failure to pursue best commercial efforts.[1] This fact coupled with the very lengthy product development cycle in the pharmaceutical business makes it difficult for outsiders to draw

1. See Grabowski and Vernon (1990) for empirical evidence on failure rates at various stages of drug development.

timely conclusions from the observed outcomes of past pairings. Second, an agent's ability to communicate negative (or positive) information about a counterparty is complicated by many factors: it may be difficult to identify the counterparty's future partners; it may be impossible to share details of opportunistic behavior publicly without revealing proprietary business plans; or the aggrieved party may not be perceived to be a credible source of information or may be seen as reliable by only a subset of potential, future collaborators. All the above factors raise the costs of sanctioning by publicizing information about a counterparty's conduct, especially when there are different plausible attributions of blame in disputes. As a result, for an agent to rely on the threat of retaliation to deter opportunistic behavior, or even for the agent to be privy to reliable information about a counterparty's reputation before entering a deal, the agent must be advantageously positioned in the established communication network.[2]

Thus, the alliance network is important because it reflects the fact that information about others' reputations is held in varying degrees by different potential counterparties. This stands in contrast to the assumptions in articles such as Klein and Leffler (1981), Kreps and Wilson (1982), Diamond (1984), and Baker et al. (2002), in which the history of each player's actions is readily observable to all agents in the model. For example, in Kali (1999), a business network is essentially a club of transactors who face zero information transmission cost with one another once an entrance fee is paid. Thus, there is no explicit role for our network measures in these models, since there is no scope for information to be variably held across actors—all members of the pool of potential counterparties know one another's reputations costlessly. Our analytical framework explicitly treats information transmission as costly and varying in proportion to the position of firms in the network.

2.3 Proximity and Centrality

We focus on two measures of the position of firms in the alliance network: proximity and centrality. Proximity is a property of pairs of firms, whereas centrality is an absolute measure. Proximity increases when fewer intermediaries separate two counterparties. More proximate firms are closer to one another in the alliance network, which means that each firm can obtain information about the other through a small number of links in the network. Centrality is a property determined by the overall shape of the network rather than by the relationship between any single pair of firms. A firm's centrality in the alliance network increases as it gains access to other influential network members.

Figure 1 illustrates the centrality and proximity measures with hypothetical networks. Network 1(a) depicts four interconnected firms: firm B links with

2. In his study of the formation of alliance networks, Gulati (1995) presents interview data showing that managers responsible for establishing alliances frequently exchange information and referrals regarding potential partners.

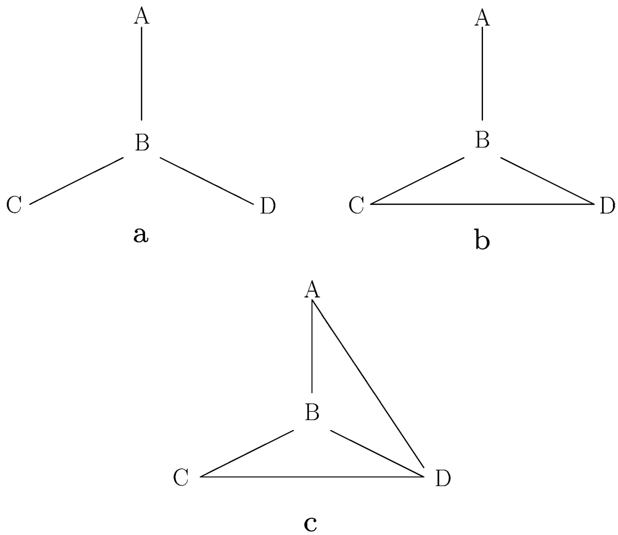

Figure 1. Examples of Networks and Network Interconnections.
Nodes in the network are denoted by letters and are connected by lines, which represent past transactions.

firms A, C, and D, but none of these three firms has formed a direct link with anyone else. In this graph, firm B is the most well-connected member of the network, since it has links to all other firms, whereas no other firm does. Firm B is thus more central than firms A, C, and D.

There are, however, multistep paths connecting firms A, C, or D, to one another, since they are all linked indirectly through firm B. Thus, for example, firms C and D have no direct links but one indirect link, since firm B must act as an intermediary between them. At the same time, it is intuitively clear that firms C and B are more proximate to one another than firms C and D, since C and B share a direct link, whereas C and D do not.

Figure 1(b) shows the same array of firms, but with an additional direct link connecting firms C and D. Intuitively, firm A is now more isolated than firms C and D, since they have direct connections not only to firm B but also to each other. Firm A's centrality is therefore lower than that of firms B and C. The proximity between D and C has also increased: before they shared an indirect link through firm B. Now they are directly connected. The number of indirect connections between firms A and C has also increased. Before, the only connection between firms A and C was through firm B; now there is an indirect three-step connection linking the two: A→B→D→C.

Finally, Figure 1(c) depicts the same network configuration as in Figure 1(b), but with an added link between firms A and D. Now firm C has two two-step links to firm A; one goes through firm B, the other through firm D. While firms B and D each have three direct links to other firms, firm B has more centrality than firm D, because the firms to which B is linked are themselves linked to more firms.

2.4 Predictions

This section extends the economic intuition behind proximity and centrality and offers predictions relating these measures to characteristics of the alliance contract. In particular, we relate proximity and centrality to the presence and size of any equity stake that the client takes in the target. We postpone formal definitions of centrality and proximity to the next section, in which we offer mathematical formulations of the graphical descriptions of proximity and centrality described above.

2.4.1 Proximity.

Proximity has a simple economic interpretation: it increases the amount of information about a counterparty available to agents at the time the contract is initiated and therefore improves the match between alliance partners. Because proximal agents have either transacted directly in the past or have engaged in transactions with an overlapping set of counterparties, they are better able to observe one another's past behavior, to learn about it at low cost from reliable sources or to impute it based on privileged knowledge of the outcomes of prior deals. Thus, when two agents who are proximate in the network enter a transaction, they do so with greater knowledge of one another's reputation and abilities than do members of more distant pairings.

Proximity also raises the sanctioning ability of the client. There is empirical evidence of serial correlation in alliance pairings (and other types of business transactions; see Gulati 1995; Uzzi 1996 and the statistics we report below). This suggests that an agent's set of current and past collaborators are its most likely future trading partners, which implies that proximate clients can levy sanctions against targets where they are most costly. Thus:

Prediction 1 (Proximity). Firms that are more proximate in the alliance network will form transactions in which the client acquires less control.

2.4.2 Centrality.

The second measure of network positioning we examine, centrality, increases when an agent has communication links to many other network members. An agent occupies a central position in a network when it has a large number of connections to other firms, which, in turn, are each linked to many other firms (Bonacich 1987). This means that central agents occupy hubs in the communication network. The economic value of centrality lies in the ability of centrally positioned agents to reduce incentive conflicts after the contract has been initiated by threatening (implicitly) to sanction opportunistic behavior.

Information disseminated by central agents travels extensively through the network. Because information that comes from central firms can reach a large audience, these agents have the greatest power to devalue the reputations of their counterparties in the set of likely, future trading partners. Consequently, in principal-agent relationships like the alliances we study, targets have the greatest incentive to avoid taking inappropriate actions when they are dealing with central clients. Understanding that their partners are deterred by their power to sanction, central agents rely on their network positions to enforce implicit agreements. In effect, both parties in a deal recognize the potential long-term reputation cost of opportunistic behavior in transactions with centrally positioned clients.

The centrality of the target also affects its incentives within any given transaction. Central firms tend to have widely known reputations and to be well regarded by other members of the network (Podolny 1993). As an agent's centrality increases, therefore, so too does the magnitude of the opportunities that it forgoes if it behaves opportunistically, and news of its transgression is transmitted across the network. Because sanctions are particularly costly for those with valuable reputations, the existence of a multilateral reputation mechanism regulates the behavior of central agents.[3]

The following prediction summarizes these observations.

Prediction 2 (Centrality). Alliances involving central clients and targets are those in which the client acquires less control.

2.4.3 Related Predictions. We have argued that the network allows costly, private information to be credibly disseminated between members of a pool of potential counterparties. Yet, targets and clients are required to disclose information publicly in order to access capital markets. Publicly traded firms have higher disclosure standards than private firms; therefore, less information is publicly available for privately held firms than for publicly traded ones. Because the information-sharing role of the network is most important in situations in which publicly available information is difficult to obtain, we offer the following prediction about public and private firms:

Prediction 3 (Information). Network effects are more pronounced in alliances with privately held targets than in deals with publicly held targets.

The predictions thus far concern the relationships between network position and the allocation of control among partners. We would also like to test the trade-off between contractual completeness and network membership, but since many of the details of actual alliance contracts are confidential, we cannot conduct a direct test of how the extensiveness of pen-and-ink controls vary with network positioning. However, we can proxy for the degree of contractual incompleteness by using the fact that R & D alliances, because they occur at an earlier stage of development, are intrinsically more difficult to govern through ex ante contracts (Pisano 1989). Thus, we can use the presence of R & D in the deal to test this trade-off indirectly. If network membership is a form of

3. In addition, as will be apparent when we derive the measures of network positioning, central firms do deals frequently. This too implies that the cost of reputation damage is greatest for central firms, as the discounted value of the expected gains from future transactions is relatively higher for these agents.

control, then reliance on the network should be particularly evident in deals in which complete contracts are most difficult to write. We should thus observe:

Prediction 4 (Complexity). Network effects are more pronounced in contractually complex transactions such as R & D alliances.

To summarize, we argue that a network allows costly information to be shared between potential transaction partners. Based on this, we argue that deals between more central and more proximal firms will involve less equity. Since the network facilitates the transmission of costly information, we expect these results to be strongest when information is the most costly to obtain: among privately held targets and among activities with the greatest potential for incomplete contracting problems.

Of course, a firm's position in the alliance network at a point in time is not exogenous; it is determined by the set of past transactions it has experienced. Certainly, many young companies desire to enter strategic alliances with central clients (which, in turn, contribute to the target company's own centrality), but only a subset of those that desire such deals are able to attract partners. Presumably, the quality of the target company in a large part determines its ability to gain access to good alliance partners.[4] To control for these effects in our regression analysis, we attempt to hold attributes like quality constant and past deal structures constant when we measure the effect of network positioning on contractual outcomes.

3. Measuring Network Positioning

In this section, we describe mathematical measures of centrality and proximity. The first step is to form a matrix comprising all firms in the industry at a point in time. The rows and columns of the matrix correspond to the set of firms in the industry, whereas alliances between firms are represented as nonzero elements in the matrix. Formally, let $N = 1,\ldots,n$ be the set of biotech firms and their partners and i and j be typical members of this set. A network of alliance links at time t can be described as a symmetric, $n \times n$ matrix as follows:

$$\mathbf{X_t} = [x_{ijt}]$$
$$x_{ijt} = x_{jit} = \left\{ \begin{array}{ll} 1, & \text{if alliance occurred,} \\ 0, & \text{otherwise,} \end{array} \right\} \tag{1}$$

4. In addition, target companies and clients incur opportunity costs when they enter alliances, and for the target company, these costs may be increasing in the client's centrality. When a target enters a deal, the contract will necessarily require that it gives up certain claims to any income stream that is produced from sales of whatever product or technology is included in the transaction. If clients who are central in the alliance network possess greater bargaining power than other firms, then they may routinely succeed at entering deals with contractual terms that favor their interests. Thus, for peripheral firms, alliance transactions involve a delicate balance between the costs of compromised bargaining power in the current deal with the gains associated with better deals in the future.

over some time period t.[5] Each row vector (or column vector, by symmetry) of $\mathbf{X_t}$ indicates the active alliances that a particular firm has formed with all other firms in the network. We call this the position vector for agent i. The symmetry of $\mathbf{X_t}$ conveys the idea that communication patterns are two-way links between agents: if agent i can communicate with j, then agent j can communicate with i. By convention, $x_{ii} = 0$; that is, a firm has zero alliances with itself, and thus, all diagonal elements are zero.

For example, in the alliance matrix corresponding to Figure 1(a), the row (or column) for firm B is $[1 \quad 0 \quad 1 \quad 1]$, whereas a row (or column) for firms A, C, or D is $[0 \quad 1 \quad 0 \quad 0]$. The added link between C and D in Figure 1(b) changes the entries for C to $[0 \quad 1 \quad 0 \quad 1]$ and D to $[0 \quad 1 \quad 1 \quad 0]$. Thus, the alliance matrix for Figure 1(b) is written as:

$$X_b = \begin{Bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{Bmatrix}. \tag{2}$$

After constructing a matrix of alliance connections, one can develop centrality, proximity, and other measures of relatedness by working with rows or columns of the matrix or by performing simple matrix transformations, as we describe below.

3.1 Centrality in the Alliance Network

The centrality of an agent depends on how many other nodes in the network the agent can reach (and by symmetry, how many can reach it) through direct and multistep paths. Central agents have many connections to other agents, who in turn are central in their own right. Following Bonacich (1987), we define an agent's centrality as:

$$\textbf{Centrality} = \mathbf{c}(\alpha, \beta) = \alpha(\mathbf{I} - \beta\mathbf{X_t})^{-1}\mathbf{X_t}\mathbf{1}, \tag{3}$$

where α is a scaling factor that is chosen to facilitate comparison across industry networks of different size, $\mathbf{1}$ is a column vector of ones, and β is the weight placed on more distant ties. The magnitude and sign of the variable β determine the extent to which the centrality of an agent's partners influences its own centrality.[6]

Since $\beta > 0$, we can rewrite equation (3) as:

$$\textbf{Centrality}(\alpha, \beta) = \alpha \sum_{k=0}^{\infty} \beta^k \mathbf{X}_t^{k-1}\mathbf{1}. \tag{4}$$

5. As we discuss is Section 4, all our network measures are calculated over a 5-year window. We have suppressed the double summation for notational convenience.

6. When $\beta = 0$, the measure is proportional to agent's i's row sum in $\mathbf{X}$. In this case, $c(\alpha, \beta)$ is proportional to the agent's alliance count. With $\beta > 0$, firms that are linked to influential firms are themselves more influential by virtue of that link. We set β equal to the three-fourths of the reciprocal of the largest eigenvalue of $\mathbf{X}$ (see Podolny [1993] or Sørenson and Stuart [2001]).

Table 1. Centrality Calculations for Figure 1 with Alternative β Assumptions

	Figure 1(a)					Figure 1(b)					Figure 1(c)				
β	0.0	0.2	0.4	0.6	0.8	0.0	0.2	0.4	0.6	0.8	0.0	0.2	0.4	0.6	0.8
Node A	0.58	0.66	0.72	0.76	0.79	0.47	0.5	0.53	0.54	0.56	0.78	0.81	0.83	0.85	0.86
Node B	1.73	1.64	1.57	1.51	1.46	1.41	1.36	1.32	1.28	1.25	1.18	1.16	1.15	1.13	1.12
Node C	0.58	0.66	0.72	0.76	0.79	0.94	0.97	1	1.02	1.03	0.78	0.81	0.83	0.85	0.86
Node D	0.58	0.66	0.72	0.76	0.79	0.94	0.97	1	1.02	1.03	1.18	1.16	1.15	1.13	1.12

This table presents Bonacich (1987) centrality calculations for each of the networks depicted in Figure 1 (see equation (3) and discussion in text). The columns associated with each figure demonstrate how centrality changes as β is varied. β is expressed as a fraction of the largest eigenvalue. α is chosen so that the squared length of $c(\alpha,\beta)$ equals the number of nodes of the matrix.

This equation shows that a firm's centrality is the sum of its immediate links, plus β times the sum of its two-step links, plus β^2 times the sum of its three-step links, and so on, ad infinitum. Thus, with $\beta > 0$, centrality is the discounted sum of all possible links between firms, with higher discount factors applying to more distant links.

To gain the intuition behind the centrality measure, it is helpful to compare centrality levels across a range of β parameters for the three networks depicted in Figure 1. Table 1 presents a comparison of β for different parameter assumptions. This table shows that the choice of β is unlikely to significantly influence the results we will report. As β is increased, there are two things to note. First, the ordinal ranking of centrality values remains unchanged. Second, the increment to a given agent's centrality resulting from a connection to a highly central partner increases.

3.2 Proximity in the Alliance Network

We calculate two measures of the proximity of each pair of firms in the alliance network. The first measure indicates the extent to which any given pair of firms in the alliance network is able to observe one another's past behavior directly. For this, we count the number of times that the two firms in a coalition at time t have engaged in alliances together prior to t. This variable is defined as:

$$\textbf{Repeat Ties} = \sum_{\tau=0}^{t} x_{ij(t-\tau)}. \tag{5}$$

The second measure of proximity gauges whether a given pair of agents are able to consult their current partners about the counterparty in the pairing. To assess this, we compute the number of active two-step paths between the two firms in an alliance. Two firms i and j are connected by a two-step path if they share a common partner k, through whom they can gain information about one another. Formally:

$$\textbf{Shared Third Parties} = \mathbf{X}_t^2 \mathbf{1_k} = \sum_{k=1}^{n} x_{ikt} x_{jkt}, \tag{6}$$

where x_{ikt}, x_{jkt} are unity if there is an active link between i, j, and k in t, and $\mathbf{1_k}$ is a vector of ones for the kth firm. In other words, looking over all other firms in the network, the number of shared third parties is the number of distinct links connecting i to j that go through exactly one intermediary.

For example, in Figure 1(b), nodes A, C, and D each have a direct link to node B, which is a shared third party for nodes A and C, nodes A and D, and nodes C and D. Nodes B and C share a third party in node D, and symmetrically, nodes D and B share a third party in C. This can be seen algebraically by taking the matrix representation of Figure 1(b), expressed in equation (2) above, and squaring it, which yields the following:

$$X_b^2 = \left\{ \begin{matrix} 1 & 0 & 1 & 1 \\ 1 & 3 & 1 & 1 \\ 1 & 1 & 2 & 1 \\ 1 & 1 & 1 & 2 \end{matrix} \right\}. \tag{7}$$

The off-diagonal elements of this matrix list the shared third-party connections described above.

Finally, we create a simple count of the number of past alliances in which a firm has engaged, which is the sum over the position vector x_i:

$$\textbf{Cumulative Alliance Count} = \sum_j x_{ijt}. \tag{8}$$

This variable is included for two reasons. First, because targets use funds pledged by alliance partners to finance growth and sustain ongoing operations, those with a high number of recent deals are likely to be better financed. Thus, the Cumulative Alliance Count is a proxy for the financial status of the target (we discuss other proxies below). Second, controlling for it is necessary to demonstrate that sanctioning and screening role of the network extends beyond the set of immediately accessible contacts.

4. Data

4.1 Background

Recombinant Capital, a biotech consulting and information services firm, is the primary source for the alliance data. Recombinant Capital scours corporate securities filings, press releases, news announcements, and other information sources to identify and characterize alliances involving biotechs, pharmaceuticals, universities, and publicly funded research labs.[7] The sample we analyze contains all 3854 strategic alliances established between biotech and pharmaceutical firms in the interval from 1976 to 1998. For these deals, we are able to obtain the basic contractual terms in each alliance, including the type of

7. Information about this data source is available online at http://www.recap.com. We cross-check the Recombinant Capital database against the Bioscan directory and the Institute for Biotechnology Information's Actions database in the early years of the industry when the Recombinant Capital data may be less complete.

agreement, whether an equity investment occurred, the amount of the equity, and the amount of funding committed by the client to support the target.

To deal with the temporal dimension of our data, some assumption about the life span of an alliance is necessary: most alliances eventually end and our data cover a 22-year period. We allow alliances to remain as "active" links for a duration of 5 years, meaning that we consider alliances to be in existence if they were established within 5 years of the current year. Thus, when we form the alliance matrix for our sample, the x_{jit} for year t are set to unity if an alliance was formed between agents i and j in the years t to $t-4$ and zero otherwise.[8]

The fact that our data go back to the origins of the industry is critical to our analysis. Without knowledge of the full history of collaborations in the sector, we could not accurately measure the extent of network connections between agents since we would arbitrarily exclude active connections that were initiated before our sample began. By starting our calculations at the inception of the industry, we avoid the problem of left truncation when we compute network variables.

4.2 The Characteristics of Alliance Contracts

We classify alliances according to whether they involve equity, R & D, or manufacturing, as well as whether funding was pledged and whether a licensing agreement was signed. The equity dummy is 1 if the client purchases an equity position in the target or if the deal is structured as a joint venture. R & D deals typically occur at an early stage in the drug-discovery process, whereas manufacturing deals (without R & D) are later stage deals. Licensing agreements are deals in which the client agrees to pay royalties to the target as potential future revenues from collaboration-based products are realized. Biotech/biotech deals are ones in which both parties are biotechnology firms.[9]

Table 2 presents frequency counts of the alliance type dummies in our sample. Reflecting the technological intensity of the sector, over half (52.4%) of all deals include R & D. Also presented in Table 2 is a breakdown of contract frequency according to whether or not funding was pledged in the deal. Milestone payments are a common feature in some types of strategic alliances; for example, over 35% of R & D alliances involve cash pledged in the form of

8. For example, the X_t matrix for the year 1996 was 1657 $\times$ 1657 because 1657 distinct firms had formed one or more alliances in the interval from 1992 to 1996. The assumption of a 5-year window seems plausible given the evidence in Robinson and Stuart (forthcoming), in which the mean contractually specified duration of biotech alliances was 3.75 years, but each contract explicitly contained provisions for extension. In addition, a 5-year window appears to be the convention in studies of intercorporate alliances (e.g., Stuart et al. [1999] or Ahuja [2000]).

9. These classifications are not mutually exclusive. For example, in September 1993 Burroughs Wellcome and Centocor formed a \$100 million alliance to develop and market Panorex, one of Centocor's monoclonal antibody–based cancer therapeutics. This deal is coded as equity, licensing, and R & D since Burroughs Wellcome (1) took a 4% stake in Centocor as part of the deal, (2) put up substantial development funds, and (3) secured a license to sell and market Panorex upon the successful completion of clinical trials.

Table 2. Frequency of Contract Characteristics

	Equity?		Cash pledged?		Equity and cash	Total
	No	Yes	No	Yes		
R & D	1555	467	1254	768	330	2022
Alliance	49.6%	64.5%	47.9%	61.9%	75.7%	52.4%
Manufacturing	153	13	129	37	8	166
Agreement	4.9%	1.8%	4.9%	3.0%	1.8%	4.3%
Licensing	1641	468	1303	806	324	2109
Agreement	52.4%	64.6%	49.8%	65.0%	74.3%	54.7%
Biotech/Biotech	856	155	790	221	67	1011
Alliance	27.3%	21.4%	30.2%	17.8%	15.4%	26.2%
Total	3133	724	2617	1240	436	3854

Agreement types are not mutually exclusive. Each cell contains the number of alliances containing the relevant characteristics. The percentages that appear below cell counts express the cell count as a percentage of the column total (the bottom row).

up-front payments made at the time a deal is established and milestone payments triggered whenever certain prespecified goals are reached. On the other hand, cash is less often pledged in later stage alliances, such as manufacturing agreements. In our data, cash is distinct from equity: deals involving equity participation may involve pledged cash (indeed, 436 of the 724 equity deals do), but cash can be pledged (and often is) without an equity ownership stake. Thus, pledged cash is not measuring the dollar value of the equity stake.

Before turning to the results, Table 3 reports descriptive statistics. The table also shows variable means broken out by the presence or absence of equity participation in an alliance. The mean levels of target centrality, number of shared third parties, and the repeat alliance count are all lower in the deals

Table 3. Summary Statistics For Analysis Variables

					Mean (X) given	
X	Mean (X)	σ (X)	Minimum	Maximum	Equity = 0	Equity = 1
Client equity count	3.07	6.04	0	43	2.59	5.18
Target equity count	1.01	1.81	0	24	0.90	1.48
Client's centrality	1.47	1.93	0	10.46	1.37	1.90
Target's centrality	0.81	1.06	0	7.77	0.87	0.53
Shared third parties	0.06	0.26	0	3	0.06	0.04
Repeat alliance count	0.11	0.45	0	7	0.12	0.09
Target publicly traded?	0.69	0.46	0	1	0.69	0.69
Target market equity	10.88	1.13	7.20	14.93	10.85	11.02
Target patents	13.10	31.53	0	474	13.64	10.73

Equity counts are the number of prior strategic alliances involving equity in which clients and targets have engaged (with any other partner). Repeat alliance count is the number of times the same two firms have engaged in prior alliances with one another. Shared third parties describes the number of third parties common to firms *i* and *j*. Target market equity is the log of the firm's market capitalization. Target patents are the cumulative number of patents issued at time $t + 2.5$ years (this accounts for the time lag between patent application and patent issuance); 3854 observations, of which 2654 involve publicly traded targets.

in which the client assumes an equity stake in the target, which is consistent with the view that clients take more control in alliances with targets that are peripheral and distant in the network. In the univariate statistics, the only exception to our predictions concerns the client's centrality, which is actually higher in alliances with equity. Appendix provides a summary of all the variables used in the analysis.

5. Sample Selection and Endogeneity

The simplest approach to analyzing the relation between contract characteristics and network positioning is to determine the in-sample relation through probit or Ordinary Least Squares regression. Most prior empirical studies examining various facets of alliance activity have in fact taken this approach (Gulati 1995), but they suffer from one important shortcoming: the observed relation between alliance contract terms and network characteristics likely reflects not only the governance role of the network but also the fact that better networked firms are more likely to be in the sample. The correlation between unobserved selection criteria and regression error in the outcome equation would then lead the uncorrected parameters to be biased estimates of the true relation between deal characteristics and the structure of the alliance network.

One approach to this problem would be to exploit a natural experiment that allowed us to observe rejected deals. We could then use these rejected deals as a control group and measure the effect of network positioning on contract characteristics relative to this control group. But such natural experiments are difficult to find in practice.

Instead, we assume that the observed data arise as a result of some unobserved search process, through which clients and targets are paired and contracts are proposed. Some contracts are accepted, whereas others are not. We observe only the accepted deals, not the rejected deals or the matches that resulted in no proposal. Viewed in this way, we can address the issue through the use of a two-stage estimation procedure that accounts for selection into the sample of observed alliances.

To estimate the sample selection equation arising from this data-generating process, we create a matched sample of firm pairs that could have established an alliance in year t but did not.[10] We then compute the centrality and proximity of the firm and firm pairings in the random sample, allowing us to estimate the probability of alliance formation as a function of network characteristics.[11] This allows us to use a Heckman (1979) approach to correct

10. For example, the biotech firm Gilead and the pharmaceutical firm Glaxo entered an alliance in 1992. Corresponding to this alliance, we drew a second random pairing consisting of one biotech firm and one pharmaceutical firm in the year 1992.

11. To ensure that the comparison sample consists only of firm pairings in which there exists a reasonable probability of an alliance, we require candidate firms to have established one or more alliances in the 5-year period prior to year t. Given the frequency of alliance activity in biotech, the majority of existing biotech firms are in the pool from which the random sample is drawn in any given year.

Table 4. Probit Analysis of Sample Selection

	Dependent variable is 1 if alliance			
	(1)	(2)	(3)	(4)
Client's centrality	0.30 (22.69)**	0.30 (21.11)**	0.28 (15.05)**	0.29 (14.31)**
Target's centrality	0.15 (8.56)**	0.08 (4.60)**	0.11 (4.26)**	0.05 (1.66)
Repeat alliance count	0.83 (9.49)**	0.81 (8.93)**	0.92 (7.56)**	0.89 (7.01)**
Shared third parties	0.28 (3.25)**	0.29 (3.26)**	0.32 (2.75)**	0.34 (2.88)**
Target university deals		0.06 (8.13)**		0.05 (5.18)**
Constant	−0.39 (18.47)**	−0.41 (18.24)**	−1.30 (40.49)**	−1.32 (38.18)**
Sampling proportion	1:1	1:1	1:5	1:5
Pseudo R^2	0.10	0.11	0.10	0.11

Probit estimates of alliance formation are reported. The dependent variable is 1 if the firm pair formed an alliance, 0 if the firm pair was not drawn from the alliance sample. Absolute value of *z*-statistics is given in parentheses. *Significant at the 5% level and **significant at the 1% level.

the sample selection problem by first estimating the probability that two firms will form an alliance and then the likelihood that the client will take an equity position in the target, conditional on the existence of the alliance.

Since we cannot know the "true" rejection rate of alliance formation in our sample, we perform robustness checks by varying the degree to which we sample nonalliance pairs relative to alliances. The first two columns of results in Table 4 present regressions from a sample of 7708 transactions: these are the 3854 alliance transactions and a matched sample of 3854 firm pairs that did not form an alliance, or a nonalliance/alliance ratio of 1:1. The third and fourth columns randomly discard alliances so that there are five nonalliances for every alliance in the sample.[12] In all subsequent tables, the sample selection correction takes place using the entire matched sample of 3854 nonalliance firm pairs, in keeping with suggestions by Imbens (1992) and King and Zang (2000) on optimal sampling proportions.

The independent variables in column (1) are the centrality of the client and the target, the number of times the pair has formed an alliance in the past, and the number of shared third parties between the firms in each pair. Each of these variables has a strong positive effect on the probability of alliance formation, across each of the four specifications in Table 4.

While the selection model is formally identified through the nonlinearity of the inverse Mills ratio, nonparametric identification requires us to find a suitable exclusion restriction for the first-stage estimation. We instrument for selection into the alliance sample by counting the number of in-licensing deals with universities that the target companies have completed prior to a given year. In-licensing deals occur when a target firm licenses a technology from a university for commercialization.

12. We obtain similar results across a wide range of specification choices for the rate of alliance formation. In tables, available upon request, we also estimate corrected logits following King and Zang (2000) and obtain results that are similar to the ones reported in the text.

Our logic for using a count of university in-licensing deals as an instrument is as follows. First, target companies that control more technology are more likely to possess intellectual property rights that are desired by potential alliance partners. In other words, the volume of past university in-licensing deals should predict inception into an alliance. Second, technology that is in-licensed does not signal the quality of the target company because it was not developed by the scientists at that firm.[13] Thus, a count of the target's past university alliances allows us to identify the sample selection equation without resorting to parametric assumptions.

Column (2) reports results from the probit regression of alliance formation on network characteristics and our target university count variable. Even when we dramatically oversample nonalliance matches relative to alliances, we see that this variable has a large and statistically significant impact on alliance formation. Thus, it is unlikely to suffer from the problems associated with weak instruments. The university in-licensing deal count variable allows us to identify the sample selection equation in the tables that follow.

6. Empirical Findings

6.1 Explaining the Use of Equity in Alliance Contracts

Table 5 presents the results from the selection-adjusted probit regressions of the probability that alliances will include equity participation (estimates for the selection equations are reported in Table 6). In the equity equations, we have broken alliance histories into two mutually exclusive components: the number of past equity alliances and the number of past, nonequity-based partnerships formed by the target and the client. The reason we make this distinction is that there are sure to be unobserved factors affecting firms' propensities to do equity-based transactions, and the counts of previous equity partnerships serve as a control to capture some of these unobserved firm differences.[14] Without the event-specific counts, these propensities would confound the alliance history effects.

Column (1) of Table 5 shows results of a regression with the centrality of the client and target in the alliance network and counts of prior equity-based alliances. Not surprisingly, the likelihood of equity is significantly higher when both the client and the target have participated in many previous equity alliances. After we control for the proclivity of clients to take equity in their alliance partners, there is a negative effect of client centrality on the probability of equity. This supports the argument that central clients can exploit their extensive reach in the network to sanction partners and therefore perceive less

13. The target firm's patent count, which we include in some of the second-stage regressions, is the other measure of the technological stock of the target that is available to us. Although patents may positively affect alliance inception, because the patent stock is an observable measure of the quality of the target, it is unlikely to be exogenous to the outcomes we study.

14. For example, some pharmaceutical firms have corporate venture capital arms that may occasionally acquire equity stakes in the firm's alliance partners. Interfirm differences such as this are the types of heterogeneity we hope to capture with the "past equity alliances" variable.

Table 5. Heckman Analysis of Equity and Network Positioning

	Dependent variable is 1 if deal contains equity					
Outcome equation	(1)	(2)	(3)	(4)	(5)	(6)
Client equity count	0.057 (7.51)**	0.066 (8.22)**	0.074 (11.92)**	0.078 (12.29)**	0.076 (12.50)**	0.075 (13.34)**
Target equity count	0.207 (10.97)**	0.190 (9.53)**	0.119 (9.18)**	0.105 (8.08)**	0.098 (7.81)**	0.095 (10.65)**
Client's centrality	−0.188 (5.03)**	−0.163 (3.73)**	−0.273 (12.46)**	−0.251 (10.91)**	−0.256 (11.76)**	−0.264 (13.86)**
Target's centrality	−0.519 (13.59)**	−0.426 (8.58)**	−0.201 (6.56)**	−0.229 (7.33)**	−0.177 (6.25)**	−0.171 (7.88)**
Client alliance count		−0.014 (2.30)*	−0.012 (3.24)**	−0.024 (5.70)**	−0.022 (5.73)**	−0.021 (6.36)**
Target alliance count		−0.031 (2.74)**	−0.033 (5.28)**	−0.027 (4.03)**	−0.024 (3.70)**	−0.018 (4.65)**
Hot equity market?		0.049 (1.08)	0.029 (1.30)	0.023 (1.00)	0.019 (0.92)	0.022 (1.42)
Repeat alliance count			−0.420 (7.93)**	−0.440 (8.07)**	−0.440 (8.09)**	−0.446 (8.28)**
Shared third parties			−0.385 (4.59)**	−0.422 (4.99)**	−0.424 (5.14)**	−0.414 (9.01)**
Pledged cash				0.010 (10.90)**	0.010 (10.85)**	0.010 (11.23)**
Licensing alliance				−0.050 (2.19)*	−0.040 (1.99)*	−0.030 (2.14)*
Manufacturing alliance				−0.143 (2.40)*	−0.115 (2.19)*	−0.082 (3.98)**
R & D alliance				0.171 (6.07)**	0.193 (6.44)**	0.173 (9.39)**
Biotech/biotech alliance				−0.066 (2.37)*	−0.051 (1.98)*	−0.032 (1.88)
R & D* (target centrality)					−0.097 (4.75)**	−0.093 (7.35)**
Target's patents						−0.002 (3.99)**
Constant	−0.170 (0.98)	0.019 (0.11)	0.620 (21.36)**	0.557 (15.44)**	0.548 (17.84)**	0.541 (20.56)**
Observations	7028	7028	7028	7028	7028	7028
Log likelihood	−6048.815	−6041.615	−6006.425	−5874.496	−5864.773	−5858.540
χ^2	276.786	305.641	723.025	803.792	841.317	1104.545

This table presents parameter estimates from maximum likelihood probit regressions of equity participation in alliance contracts. The dependent variable is a dummy variable that takes on the value 1 if the client purchased equity in the target or if the deal was structured as a joint venture. The independent variables are defined in Table 2 with the exception of hot equity market. This variable is unity in the years 1983, 1986, 1987, 1991, 1992, and 1996, and zero otherwise. See Lerner (1994) for more details. In all, 7708 observations are included, equally split between true alliances and nonalliance pairs. See Table 6 for parameter estimates in the underlying selection equation for each column. The *t*-statistics are reported in parentheses. *Significant at the 5% level and **significant at the 1% level.

Table 6. Sample Selection Equation in Table 5

	Dependent variable is 1 if alliance					
Selection equation	(1)	(2)	(3)	(4)	(5)	(6)
Client centrality	0.309 (21.36)**	0.311 (21.59)**	0.307 (22.89)**	0.305 (22.90)**	0.304 (23.01)**	0.306 (23.12)**
Target centrality	0.096 (5.00)**	0.102 (5.14)**	0.150 (7.77)**	0.149 (7.61)**	0.156 (7.69)**	0.171 (9.69)**
Repeat alliance?	0.763 (8.01)**	0.737 (7.52)**	0.653 (8.06)**	0.657 (8.16)**	0.623 (7.75)**	0.596 (7.43)**
Shared third parties	0.241 (2.65)**	0.228 (2.53)*	0.282 (3.38)**	0.328 (3.96)**	0.340 (4.13)**	0.345 (7.90)**
University deals	0.058 (7.75)**	0.058 (7.61)**	0.030 (4.40)**	0.023 (3.28)**	0.018 (2.47)*	0.011 (2.07)*
Constant	−0.418 (18.57)**	−0.421 (18.71)**	−0.423 (19.27)**	−0.415 (18.96)**	−0.415 (18.97)**	−0.418 (19.66)**
a tan(ρ)	−0.525 (2.92)**	−0.658 (3.37)**	−2.408 (9.14)**	−2.411 (9.08)**	−2.915 (5.27)**	−9.050 (0.27)

This table reports parameter estimates from the first-stage selection equations corresponding to the equations estimated in Table 5. The estimation is based on a matched sample of alliance and nonalliance pairs. We jointly estimate the probit regression and selection equation following Van de Ven and Van Pragg (1981). The variable ρ is the correlation between the error terms in the selection and regression equations, and the function *a* tan(ρ) is defined by $a\tan(\rho) = \frac{1}{2}\ln\left(\frac{1+\rho}{1+\rho}\right)$. The *t*-statistics are reported in parentheses. *Significant at the 5% level and **significant at the 1% level.

need for equity control. In accordance with the hypothesis that clients will perceive a lower risk of transacting with agents who are deeply immersed in the network, target centrality also has a statistically significant, negative effect on the probability of equity.

Column (2) introduces a number of control variables. In particular, we include a count of the number of alliances done by the client and target each during the previous 5 years to capture differences in the level of funding provided by existing alliance partners and a dummy variable signifying whether or not the biotech equity markets are strong at the time of the deal, as suggested by Lerner (1994).[15] Including these controls does reduce the point estimate on target centrality, but it remains statistically significant at the 1% level regardless of how the regression equation is specified. Moreover, the addition of the controls does not attenuate the client centrality effect.

Column (3) reports the effects of the number of repeat alliances between the pair and the number of shared third parties between the target and client. The results support Prediction 2: firm pairings that have done an alliance in the past and those that share common third parties have a statistically significantly lower likelihood of equity. Thus, the results support the idea that proximity in the network improves the client's match with the target: clients paired with proximate targets appear to be less concerned about opportunistic behavior on the part of the target. The closer in the network are the firms in an exchange, the lower is the probability of equity in the alliance.

Column (4) in Table 5 shows that alliance type is also an important determinant of the presence of equity in the alliance contract. Of particular interest are the coefficients on the R & D and manufacturing dummy variables. Consistent with arguments in Pisano (1989), there is a higher probability of equity in R & D alliances; equity control is more likely in deals for which ex ante contracts are especially difficult to write. The negative coefficient on the manufacturing dummy also accords with the argument that equity is a method of circumventing opportunistic behavior. Because manufacturing deals occur at a later stage of product development and therefore involve fewer uncertainties and information asymmetries, more comprehensive contracts can be written to govern these agreements. The lower incidence of equity in this type of transaction is therefore not surprising.

The licensing dummy provides additional evidence on the use of contract design for aligning incentives. The licensing dummy equals unity whenever the alliance contract gives the target a share of future drug revenues through a licensing agreement. The negative significant loading suggests that providing the target with project-level cash flow rights (i.e., a stake in the licensing

15. This variable is unity in the years 1983, 1986, 1987, 1991, 1992, and 1996, and zero otherwise. Based on analysis in Lerner (1994), these are the 6 years in the 20-year period of our data when the public equity markets were most welcoming to biotech issues: the incidence of Initial Public Offerings (IPOs) was high in these years and target valuations were also high. Lerner (1994) argues that the availability of many external financing options strengthens the target's bargaining position in alliance negotiations, which may affect the allocation of control and level of pledged funding in deals.

revenues of the drug produced through the collaboration) reduces the need for the client to take an equity position to monitor effort or resolve holdup problems. However, the presence or absence of licensing provisions does not affect our results linking equity to network proximity or centrality.

Column (5) in Table 5 reports an interaction effect that allows us to test Prediction 4. This regression incorporates an interaction between the R & D dummy and target centrality, which is negative and statistically significant. This demonstrates that the amount of information available about the target through the network has the strongest effect on lowering the probability of an equity investment in precisely the type of alliances where contractual uncertainty is at its greatest; namely, in R & D alliances. Conversely, the results show that the effect of high uncertainty (R & D) on the probability of equity participation is largely offset by high target centrality and proximity. In fact, a 1-SD shift in target centrality erases roughly half the positive effect of the R & D dummy on the probability of equity. R & D deals involving targets with centrality scores at or above 2 SD from the mean are no more likely to involve equity than non–R & D deals.

The economic effects of these findings are large. The point estimates from the models estimated in Table 5 suggest that, at the mean, the marginal effect of target centrality ranges from 9% to 12%, depending on the model specification. The marginal effect of shared third parties is about 15%; at the mean, a 1-SD shift in the number of shared third parties lowers the probability of equity by about 5%. Given that the unconditional mean proportion of equity in our sample is around 17%, this suggests that centrality and proximity have economically, as well as statistically, significant effects on the presence of equity in an alliance.

6.2 Equity Participation and Control

The results presented in Table 5 only distinguish between equity and nonequity deals. They leave open the question of how much control is really being acquired in these transactions. More precisely, equity ownership affords two types of property rights in varying degrees: residual income rights and control rights. Although aligning a client's residual income rights may be important for the alliance target (it may, e.g., lower the client's desire to expropriate the target), Grossman and Hart (1986) and Aghion and Tirole (1994) show that residual income rights alone do not solve the incentive problems posed by incomplete contracts. Instead, control over how assets are deployed is required, and this is an increasing function of equity ownership: large shareholders not only have more voting influence but also, as noted earlier, often gain access to the board of directors (Allen and Phillips 2000).

Indeed, Robinson and Stuart (forthcoming) examine contractual details for a sample of 125 alliances and provide evidence suggesting that explicit control rights are more common when equity stakes are larger. In particular, some deals involving equity also afford the client a seat on the target's board of directors. Board seats appear to be more common as the equity stake grows: in their data, the 69 equity transactions with no board seats had a mean stake size of roughly 6%; the 11 transactions with a single board seat, 11%; and the lone deal with two board seats, a 20% stake size.[16] Thus, by expressing equity participation in terms of the size of the equity stake, we can more closely examine the issue of control.

We explore this in Table 7. This table restricts the alliance sample to deals done by publicly traded targets. For this subsample, we are able to calculate the client's equity position as a fraction of the target's total market equity and estimate selection-corrected tobit regressions. Among the 415 equity transactions involving publicly held targets, the mean stake size was 19.9%. This suggests that control rights were indeed salient in the equity allocation for the average deal in our sample.

These findings echo those obtained from the equity probit regressions presented in Table 5. In each of the regressions reported, target centrality has a strong, negative effect on the fraction of equity purchased by the target. Likewise, centrally located clients also take smaller equity stakes in their partners. In column (2), we include the client and target alliance counts, as well as the repeat alliance count and the number of shared third parties.

The regression in column (3) adds the vector of deal characteristics, as well as the dummy for hot equity markets. It shows that clients acquire larger equity stakes in R & D alliances. This matches the results from the equity probit regressions: clients not only take equity positions in R & D alliances more often but also take larger equity positions in R & D alliances. Likewise, in column (4) we include the interaction of R & D and target centrality, which continues to be negative, although insignificant. That is, not only is equity less common in R & D alliances with centrally located targets, but the equity stakes are smaller when they are taken.

Focusing on the subsample of publicly owned targets allows us to introduce several variables that proxy for the target's financial strength and its need for outside funding. In columns (5)–(7) we include the log of the biotech firm's market equity. Even controlling for firm size, the network effects still hold. As an additional control, we introduce the amount of cash on the target's balance sheet (Compustat item 210) in equations (6) and (7). Fractional equity participation loads negatively on it, but it is not statistically significant. We conclude from this that the results are robust to controls for firm size and financial security.[17]

Of course, Table 7 restricts attention to publicly traded firms. As we later show, network effects are less salient for these firms. To ensure that we are getting to the heart of the control rights issue, we repeated the analysis of Table 7,

16. The data in Robinson and Stuart (forthcoming) also demonstrate within-contract variation in control rights. A number of contracts explicitly vary board seats with the size of the equity stake held by the partner, and contracts frequently place an upper limit on the total size of the equity stake taken by the client, suggesting a need to limit overall control.

17. The inverse Mills ratio in each equation is based on a first-stage regression of the probability of alliance on centrality, repeat alliance count, shared third parties, and university in-license deal count.

Table 7. Proportional Equity Ownership and Network Characteristics

	Dependent variable is % of target's equity purchased by client						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Client equity count	0.022 (3.95)**	0.030 (4.62)**	0.027 (4.23)**	0.026 (4.17)**	0.026 (4.24)**	0.029 (3.65)**	0.029 (3.65)**
Target equity count	0.113 (8.68)**	0.112 (8.33)**	0.090 (6.86)**	0.090 (6.84)**	0.091 (7.10)**	0.082 (5.14)**	0.082 (5.14)**
Client's centrality	−0.077 (3.08)**	−0.092 (3.02)**	−0.064 (2.13)*	−0.062 (2.04)*	−0.064 (2.19)*	−0.102 (2.68)**	−0.103 (2.69)**
Target's centrality	−0.326 (9.76)**	−0.271 (6.80)**	−0.252 (6.45)**	−0.236 (5.65)**	−0.235 (5.72)**	−0.199 (3.98)**	−0.200 (3.98)**
Client alliance count		−0.008 (1.62)	−0.011 (2.28)*	−0.011 (2.27)*	−0.012 (2.42)*	−0.007 (1.09)	−0.007 (1.08)
Target alliance count		−0.020 (1.99)*	−0.012 (1.20)	−0.011 (1.10)	−0.010 (1.07)	−0.002 (0.14)	−0.002 (0.16)
Repeat alliance count		−0.162 (3.40)**	−0.113 (2.49)*	−0.108 (2.36)*	−0.117 (2.58)*	−0.121 (2.15)*	−0.121 (2.16)*
Shared third parties		−0.178 (2.13)*	−0.203 (2.53)*	−0.207 (2.57)*	−0.195 (2.49)*	−0.177 (1.89)	−0.177 (1.89)
Pledged cash			0.006 (9.46)**	0.006 (9.19)**	0.006 (9.59)**	0.006 (7.45)**	0.006 (7.45)**
Manufacturing alliance			−0.526 (2.99)**	−0.526 (2.98)**	−0.516 (3.00)**	−0.624 (2.37)*	−0.624 (2.37)*
Licensing alliance			0.047 (1.22)	0.051 (1.32)	0.053 (1.42)	0.123 (2.37)*	0.123 (2.37)*
R & D alliance			0.110 (2.79)**	0.135 (2.84)**	0.144 (3.09)**	0.217 (3.24)**	0.215 (3.17)**
Hot equity market?			−0.027 (0.71)	−0.028 (0.73)	−0.029 (0.78)	−0.008 (0.15)	−0.007 (0.14)
R & D* (target centrality)				−0.035 (0.95)	−0.037 (1.02)	−0.102 (2.13)*	−0.101 (2.08)*
ln(target market cap)					−0.061 (3.85)**	−0.076 (3.21)**	−0.076 (3.20)**
ln(target cash, BS)						−0.019 (1.22)	−0.019 (1.19)
Target's patents							−0.000 (0.22)
Inverse Mills ratio	−0.378 (3.60)**	−0.687 (5.10)**	−0.470 (3.56)**	−0.458 (3.46)**	−0.502 (3.85)**	−0.631 (3.68)**	−0.633 (3.69)**
Constant	−0.244 (2.34)*	0.103 (0.74)	−0.184 (1.27)	−0.212 (1.44)	0.499 (2.14)*	0.592 (1.84)	0.596 (1.85)
Observations	2473	2473	2465	2465	2465	1689	1689
Pseudo R^2	0.101	0.111	0.182	0.182	0.190	0.198	0.198

BS, balance sheet. Selection-corrected tobit estimates are reported. The dependent variable is the fraction of target's outstanding market equity purchased by the client firm. The inverse Mills ratio is included to correct for the sample selection induced by the alliance formation process. The selection equation underlying the inverse Mills ratio regresses alliance participation on 5-year client and target alliance count, number of shared third parties, repeat alliance count, and the number of university in-licensing agreements. A total of 2565 observations are included, corresponding to the number of deals struck with publicly traded targets. *Significant at the 5% level and **significant at the 1% level. Absolute values of *t*-statistics are reported below point estimates.

but replaced the proportion of equity with the dollar value of the equity stake as the dependent variable. While this dependent variable lacks a sense of proportionality, it is defined for privately held firms, where no market value is observable. The results from this exercise are suppressed for the sake of brevity, but echo those reported in Table 7.

The findings from this section indicate that network positioning affects client equity participation not only on the extensive margin but also on the intensive margin as well. Centrally located clients are less likely to use equity, and when they do acquire equity stakes, they take smaller positions.

6.3 Alternative Explanations

There are a number of potential alternative interpretations of the finding that network centrality diminishes the likelihood that clients acquire equity stakes in targets. One possible motivation for why clients sometimes purchase equity is that they wish to exploit privileged information about undervalued alliance partners. If this were correct, more centrally positioned clients would take larger, not smaller, equity stakes, insofar as their high centrality gives them increased bargaining power in alliance negotiations, access to greater amounts of private information about targets, or both. Thus, the results from Table 5 suggest that either this explanation does not capture the dominant motivation for equity ownership or this effect is subsumed in the count of previous equity alliances.

There are other alternative explanations for the centrality findings as well. One is that targets with better network positions are simply better quality firms. Higher quality strengthens bargaining power, and thus more central targets do not cede as many control rights. As a proxy for the quality of the target, we include a count of the patents that have been filed by the target in column (6) of Table 5, and column (7) of Table 7. Complete patent histories for the targets in our sample were obtained from the IBM Intellectual Property Database. Although patents are an imperfect measure of innovation, they represent the only reliable quality measure that is available for all (public and private) firms in the data.

The correlation between target patents and target centrality is 0.28, suggesting that there is reason to suspect that well-positioned targets are indeed ones with a high degree of research competence. Column (6) of Table 5 repeats the regression estimated in column (5), except that it includes the patents variable. Equity participation loads negative and statistically significantly on the number of target patents, as one would expect. However, including target patents does not diminish the statistical significance of the network variables. Target centrality, repeat alliance count, and the number of shared third parties still remain statistically significant and have a negative impact on equity participation.[18] Column (7) of Table 7 tells a similar story with respect to the

18. In unreported tables, we show that each of the first seven regressions estimated in Table 5 demonstrates the same effect: equity participation loads negatively on the number of patents, and none of the network variables loses statistical significance.

proportion of equity purchased, including a control for the quality of the target has no effect on the significance of the network variables.

Another interpretation of the centrality variable is that it simply proxies for bargaining power in ways not captured by quality measures. Consistent with Lerner and Merges (1998), Lerner and Elfenbein (2003), and others, our results show a negative relation between prior alliance activity and the use of equity. This shows that client firms exercise fewer control rights in deals when target firms have more bargaining power, supporting the bargaining power predictions of Aghion and Tirole (1994).

Tables 5 and 7 include a range of controls for this possibility. The pairwise transaction histories included in Table 5 are one source of controls for this interpretation. Without controlling for these immediate linkages, it would be difficult to distinguish our story from a simpler bargaining power explanation along the lines of Aghion and Tirole (1994), since our network variables would be measuring broader network characteristics as well as the immediate set of past transactions of a target or client. However, by including these variables we not only offer additional evidence supporting the property rights–based explanations cited in prior empirical work but also strengthen our interpretation that network effects alter the governance structure of strategic alliances.

Yet another possible interpretation is that targets that have participated in many alliances in the past seek less external funding and so are less willing to give up equity control to their partners in exchange for an investment. Tables 5 and 7 also include controls that measure the availability of financial markets and inside funding, controlling for this possibility, or the possibility that peer funding is being driven by pecking-order considerations (Myers 1984): under asymmetric information, firms may prefer one method of raising capital over others because of the information revelation that certain financing decisions induce. Our centrality findings are robust to introducing controls for access to external financing: the centrality and proximity results are negative and significant when we introduce the Lerner index for whether equity markets were receptive to biotechnology IPOs, as well as a dummy for whether the target is publicly held. Moreover, the centrality and proximity results still hold when we introduce controls for the strength of the target's internal financial position. Thus, although bargaining power clearly seems important for understanding financial structure, controlling for this alternative does not diminish our central findings.[19]

To address this alternative more directly, we model the amount of cash pledged in the alliance as a function of network variables and other controls. This is presented in Table 8. Under the hypotheses we have put forward, better networked firms would presumably command larger amounts of pledged cash, as better networked firms would enter into alliance agreements in which more

19. Another possibility is that fads in deal structure induce a spurious correlation between the presence of equity and network positioning. This might be the case if equity participation were trending upward over time. To control for this, in unreported tables we have estimated our models with a full set of year dummies. Our results are unchanged. We are grateful to the referee for pointing this out.

Table 8. Pledged Cash and Network Characteristics

	Dependent variable is cash pledged to target by client				
	(1)	(2)	(3)	(4)	(5)
Client's centrality	−0.654 (0.78)	−0.623 (0.74)	−0.561 (0.68)	0.437 (0.43)	0.602 (0.60)
Target's centrality	2.596 (2.87)**	3.145 (3.48)**	2.490 (2.77)**	1.039 (0.96)	0.664 (0.61)
Repeat alliance count	−0.563 (0.29)	−0.009 (0.00)	−0.764 (0.40)	−0.740 (0.34)	−0.715 (0.33)
Shared third parties	3.562 (1.04)	4.000 (1.17)	6.827 (2.00)**	9.013 (2.19)**	7.320 (1.77)
Client took equity stake?	37.563 (18.10)**	36.355 (17.57)**	35.501 (17.33)**	35.709 (13.89)**	35.827 (14.02)**
Manufacturing alliance		−3.814 (0.76)	−4.466 (0.90)	−3.125 (0.53)	−3.267 (0.55)
Licensing alliance		9.057 (4.73)**	8.500 (4.47)**	8.455 (3.54)**	8.541 (3.60)**
R & D alliance		7.523 (3.95)**	6.678 (3.53)**	7.671 (3.23)**	7.973 (3.37)**
Biotech/biotech alliance			−15.995 (7.13)**	−15.370 (5.05)**	−15.662 (5.17)**
Hot equity market?			−0.744 (0.40)	−1.733 (0.74)	−1.838 (0.80)
Target cash, BS				0.010 (0.95)	0.013 (1.19)
ln(target market cap)				2.359 (2.37)*	1.886 (1.89)
Target's patents					0.209 (3.62)**
Inverse Mills ratio	−33.303 (5.90)**	−29.145 (5.16)**	−27.698 (4.95)**	−24.744 (3.57)**	−23.247 (3.37)**
Constant	−11.281 (2.05)*	−23.410 (4.04)**	−18.740 (3.23)**	−46.116 (3.42)**	−43.253 (3.23)**
Pseudo R^2	0.033	0.037	0.041	0.038	0.039
Full sample?	Yes	Yes	Yes	Publicly traded only	

BS, balance sheet. Selection-corrected tobit estimates are reported. The dependent variable is the amount of funding pledged in each alliance contract, which includes up-front payments as well as any contingent payments that are pledged at the inception of the contract. In columns (1)–(3), 3854 observations are included in each regression, of which 2616 are left-censored at pledged cash = 0. In columns (4) and (5), the subset of alliances involving publicly traded targets is used (2565 observations). The inverse Mills ratio is included to correct for the sample selection induced by the alliance formation process. The selection equation underlying the inverse Mills ratio regresses alliance participation on 5-year client and target alliance count, number of shared third parties, repeat alliance count, and the number of university in-licensing agreements. Absolute value of *z*-statistics are given in parentheses. *Significant at the 5% level and **significant at the 1% level.

resources are subject to holdup. Under the alternative described here, better networked firms would seek smaller cash pledges.

Three key findings emerge from this table. The first is that increased target centrality does not lower pledged funding; it raises it. After controlling for equity, we see that target centrality has a statistically significant effect on the amount of funding pledged. Target centrality is also economically important. At the mean, a 1-SD increase in target centrality raises pledged funding by about $2.5 million. This is roughly one-third of the average pledged cash of $7.7 million and above the 75th percentile for pledged cash, $2 million.

The second key finding is that publicly held firms receive more, not less, pledged cash. Thus, rather than public firms having a lower demand for external capital than smaller, private firms, public ownership status is correlated with lower costs of obtaining information about the target because public firms tend to be older and are subject to more external verification mechanisms (e.g., Securities and Exchange Commission reporting standards) than young, private companies.[20] Indeed, from columns (5) and (6) we see that pledged cash loads positively and significantly on the target's market equity. This corroborates the interpretation that larger, publicly traded targets are perceived to be safer transaction partners.

The third key finding is that limiting the regressions to the set of publicly traded firms attenuates the effect of target centrality. Centrality is much higher, and less variable, for publicly traded than for privately held targets. The mean target centrality for publicly traded firms is over twice that of private firms (0.987 versus 0.400, respectively), whereas the coefficient of variation is roughly two-thirds that of privately held firms (1.14 versus 1.78, respectively). Thus, variation in target centrality is most important for explaining funding among firms that are not publicly traded. The fact that our results are sharper for nonpublicly traded firms supports Prediction 3.

7. Discussion and Conclusion

In this article we argue that the stock of past alliances in the biotechnology industry forms a communications network that affects the structure and size of alliance agreements between any two given firms in the industry at a point in time. We show that when two counterparties are closely linked in the alliance network, or when one of the counterparties is deeply embedded within it, the deals they consummate are less likely to involve equity participation and typically entail lower amounts of equity when equity is used. Moreover, research firms that are deeply embedded within the network receive more funding pledges from clients. Indeed, when the potential for agency problems is most severe, the role of the alliance network as a substitute for equity ownership is most noticeable.

20. A related possibility is that publicly traded firms are able to bargain for larger amounts of funding without giving up additional rights to clients. However, the hot equity market dummy offers the cleanest test of the bargaining power explanation, and we find that the coefficient attached to it is statistically insignificant.

Of course, this raises an obvious question: why do firms not attempt to manipulate their position in the network to facilitate more favorable governance arrangements? If particular network positions are advantageous for creating desired outcomes, then there would be strong incentives for firms to alter their positions in the network. Moreover, interfirm differences in network positions may reflect other underlying sources of heterogeneity that enable some firms to create advantageous relationships, but not others.

Endogeneity may be less of an issue in our analysis than in other empirical settings in which the outcome measure is clearly performance related, and thus, incentives to manipulate the network are strong. Since it is unclear a priori which types of governance outcomes would be more favorable to clients and biotech research firms in our study, we believe that the incentive to strategically alter network positions are not as strong and clear cut in our context as they might be in other empirical settings. But we nonetheless attempt to address endogeneity-related concerns through a variety of means.

We control for potential sample selection issues by modeling the probability of observing an alliance in our data as a function of network characteristics. This allows us to separate the effects of network positioning on governance from the underlying relation between network positioning and alliance formation. We control for unobserved heterogeneity in preferences for deal structure by including counts of past equity alliance activity. And we control for target firm quality by including a measure of the firm's patent history. Our findings are robust to these controls. Nevertheless, any causal interpretation of our findings must be tempered by the fact that firms may be judiciously choosing governance structures to affect future network positioning in some way that we cannot measure.

These findings demonstrate that the economic opportunities a firm faces as a function of its position in the alliance network help to shape the governance of individual strategic alliances. The logic of these results is simple. It is well known that the opportunity for repeated interaction can mitigate some of the incentive problems that plague one-shot transactions. Embedding individual contracts in a network of past alliances creates opportunities for agents to levy long-term reputational penalties against their counterparties, even when they have no intention of entering into future transactions with the counterparty in the present collaboration. Within the framework of an alliance network, a firm must weigh the benefits of taking actions that are beneficial to itself at the expense of its counterparty not only against the lost opportunities with that firm but also against the lost opportunities with other firms that can be reached within the network.

Crocker and Reynolds (1993) argue that efficient contracts optimally balance the costs associated with contracting against the potential for future holdup. Our results suggest that increased access to the alliance network shifts the balance toward less complete contracts that instead rely on extracontractual enforcement mechanisms, rather than contractual specificity, to prevent holdup from occurring. This supports theoretical predictions from the relational contracting literature (Baker et al. 1999, 2002). Indeed, the network effects we identify are suggestive of the implicit contracts that Baker et al. (2002) argue may be more salient between firms than within firms.

Appendix

Table A1. Variables Used in the Analysis

Variable	Definition
Equity dummy	= 1 if the client took an equity stake in the target firm, 0 otherwise.
Proportional equity stake	The ratio of equity stake size to total market value of target's equity (defined only for publicly traded targets).
Pledged cash	The dollar value of the total cash pledged from the client to the target.
R & D alliance	= 1 if the deal concerned R & D.
Manufacturing agreement	= 1 if the deal concerned manufacturing a drug or chemical entity (typically such deals occur at later stages than R & D deals).
Licensing agreement	= 1 if the client licensed a technology from the target
Biotech/biotech alliance	= 1 if both client and target are biotechnology firms, in contrast to when the client is a pharmaceutical firm and the target is a biotechnology firm.
Client equity count	The number of past deals in which the client firm took an equity stake in its partner.
Target equity count	The number of past deals in which the target firm sold an equity stake to its partner.
Shared third parties	The number of connections between a client and target that arise through a common partner.
Repeat alliance count	A count of prior alliance transactions between the focal target and client firm.
Client's/target's centrality	Firms with ties to more influential partners have higher centrality scores. Centrality is positively correlated with the number of past deals but will vary according to whether the partners in past deals have themselves entered into many alliances. This measure captures the idea that a past alliance with an influential partner may be more valuable than an alliance with a relatively unknown client.
Target publicly traded	= 1 if the target is publicly traded.
Target market equity	The total market value of equity for publicly listed target firms.
Target patents	The number of patents held by the target firm. Data obtained from the IBM Intellectual Property database.
Target university deals	The number of in-licensing deals the target has done with university research labs.
Target cash, BS	The total amount of cash on the target's balance sheet. Only available for firms listed on Compustat.
Inverse Mills ratio	Corrects for sample selection bias. Is obtained from a probit regression of a dummy for whether an alliance occurred on the following independent variables: target and client centrality, shared third parties, repeat alliance count, and target university deal count.

BS, balance sheet.

References

Aghion, P., and J. Tirole. 1994. "The Management of Innovation," 109 *Quarterly Journal of Economics* 1185–209.

Ahuja, G. 2000. "The Duality of Collaboration: Inducements and Opportunities in the Formation of Interfirm Linkages," 21 *Strategic Management Journal* (March) 317–43.

Allen, J.W., and G.M. Phillips. 2000. "Corporate Equity Ownership, Strategic Alliances, and Product Market Relationships," 55 *Journal of Finance* (December) 2791–815.

Arruñada, B., L. Garicano, and L. Vázquez. 2001. "Contractual Allocation of Decision Rights and Incentives: The Case of Automobile Distribution," 17 *Journal of Law, Economics, and Organizations* 257–84.

Baker, G., R. Gibbons, and K.J. Murphy. 1999. "Informal Authority in Organizations," 15 *Journal of Law, Economics, and Organizations* 56–72.

———. 2002. "Relational Contracts and the Theory of the Firm," 117 *Quarterly Journal of Economics* (February) 39–84.

———. 2004. "Strategic Alliances: Bridges Between 'Islands of Conscious Power'," Working Paper, Harvard Business School.

Bonacich, P. 1987. "Power and Centrality: A Family of Measures," 92 *American Journal of Sociology* 1170–82.

Boone, A. 2001. "The Interaction of Ownership, Governance, and Product Markets: Evidence from Equity Carve-Outs," Working Paper, Penn State University.

Corts, K., and J. Singh. 2004. "The Effect of Repeated Interaction on Contract Choice: Evidence from Offshore Drilling," 20 *Journal of Law, Economics, and Organization* (April) 230–60.

Crocker, K., and K.J. Reynolds. 1993. "The Efficiency of Incomplete Contracts: An Empirical Analysis of Air Force Engine Procurement," 24 *The Rand Journal of Economics* (Spring) 126–46.

Diamond, D. 1984. "Financial Intermediation and Delegated Monitoring," 51 *Review of Economic Studies* 393–414.

Ellickson, R. 1991. *Order Without Law.* Cambridge, Mass.: Harvard University Press.

Grabowski, H., and J. Vernon. 1990. "A New Look at Returns and Risks in Pharmaceutical R&D," 36 *Management Science* (July) 804–21.

Greif, A. 1989. "Reputation and Coalitions in Medieval Trade: Evidence on the Maghribi Traders," 49 *Journal of Economic History* 857–82.

———. 1991. "The Organization of Long-Distance Trade: Reputation and Coalitions in the Geniza Documents and Genoa During the Eleventh and Twelfth Centuries," 51 *Journal of Economic History* 459–62.

———. 1993. "Contract Enforceability and Economic Institutions in Early Trade: The Maghribi Traders' Coalition," 83 *The American Economic Review* 525–48.

Grossman, S., and O. Hart. 1986. "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," 94 *Journal of Political Economy* 691–719.

Gulati, R. 1995. "Does Familiarity Breed Trust? The Implications of Repeated Ties for Contractual Choice in Alliances," 38 *Academy of Management Journal* 85–112.

Heckman, J.J. 1979. "Sample Selection Bias as a Specification Error," 47 *Econometrica* 153–61.

Imbens, G. 1992. "An Efficient Method of Moments Estimator for Discrete Choice Models with Choice-Based Sampling," 60 *Econometrica* 1187–214.

Johnson, S., J. McMillan, and C. Woodruff. 2002. "Courts and Relational Contracts," 18 *Journal of Law, Economics, and Organizations* 221–77.

Kali, R. 1999. "Endogenous Business Networks," 15 *Journal of Law, Economics, and Organizations* 615–36.

King, G., and L. Zang. 2000. "Logistic Regression in Rare Events Data," 9 *Political Analysis* (December) 1–27.

Klein, B., and K.B. Leffler. 1981. "The Role of Market Forces in Assuring Contractual Performance," 89 *Journal of Political Economy* (August) 615–41.

Kreps, D., and R. Wilson. 1982. "Reputation and Imperfect Information," 27 *Journal of Economic Theory* (August) 253–79.

Lerner, J. 1994. "Venture Capitalists and the Decision to Go Public," 35 *Journal of Financial Economics* 293–316.

Lerner, J., and D. Elfenbein. 2003. "Ownership and Control Rights in Internet Portal Alliances: 1995–1999," 34 *The Rand Journal of Economics* 356–69.

Lerner, J., and R.P. Merges. 1998. "The Control of Strategic Alliances: An Empirical Analysis of Biotechnology Collaborations," 46 *Journal of Industrial Economics* 125–56.

Myers, S. 1984. "The Capital Structure Puzzle," 39 *Journal of Finance* 575–92.

National Science Board. 2000. "Science and Engineering Indicators—2000," Technical Report NSB-00-1, National Science Foundation, Arlington, Va.

National Science Foundation. 1997. "Research and Development in Industry: 1994," Detailed Statistical Tables NSF 97-331, National Science Foundation, Division of Science Resources Studies, Arlington, Va.

Oxley, J.E. 1997. "Appropriability Hazards and Governance in Strategic Alliances: A Transaction Cost Approach," 13 *Journal of Law, Economics, and Organizations* 387–409.

Pisano, G. 1989. "Using Equity Participation to Support Exchange: Evidence from the Biotechnology Industry," 5 *Journal of Law, Economics, and Organization* 109–26.

Podolny, J.M. 1993. "A Status-Based Model of Market Competition," 98 *American Journal of Sociology* 829–72.

Rajan, R., and L. Zingales. 1998. "Power in a Theory of the Firm," 113 *Quarterly Journal of Economics* 387–432.

Raub, W., and J. Weesie. 1990. "Reputation and Efficiency in Social Interactions," 93 *American Journal of Sociology* 626–54.

Robinson, D.T. 2001. Strategic Alliances and the Boundaries of the Firm. Ph.D. thesis, University of Chicago Graduate School of Business, Chicago, Ill.

Robinson, D.T., and T.E. Stuart. Forthcoming. "Financial Contracting in Biotech Strategic Alliances," Working Paper, Columbia University.

Sørenson, O., and T.E. Stuart. 2001. "Syndication Networks and the Spatial Distribution of Venture Capital Investments," 106 *American Journal of Sociology* 1546–86.

Stuart, T., H. Hoang, and R. Hybels. 1999. "Interorganizational Endorsements and the Performance of Entrepreneurial Ventures," 44 *Administrative Science Quarterly* (June) 315.

Uzzi, B. 1996. "The Sources and Consequences of Embeddedness for the Economic Performance of Organizations: The Network Effect," 61 *American Sociological Review* (August) 674–98.

Van de Ven, W.P.M.M., and B.M.S. Van Pragg. 1981. "The Demand for Deductibles in Private Health Insurance: A Probit Model with Sample Selection," 17 *Journal of Econometrics* 229–52.

Williamson, O. 1975. *Markets and Hierarchies: Analysis and Anti-Trust Implications.* New York, N.Y.: The Free Press.

Wu, Y. 2001.The Choice Between Public and Private Equity Offerings. Ph.D dissertation, University of Chicago Graduate School of Business, Chicago, Ill.