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THE DUALITY OF COLLABORATION: INDUCEMENTS AND OPPORTUNITIES IN THE FORMATION OF INTERFIRM LINKAGES

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I argue that the linkage-formation propensity of firms is explained by simultaneously examining both inducement *and* opportunity *factors. Drawing upon resource-based and social network theory literatures I identify three forms of accumulated capital*—technical, commercial, *and* social—*that can affect a firm's inducements and opportunities to form linkages. Firms possessing these capital stocks enjoy advantages in linkages formation. However, firms lacking these accumulated resources can still form linkages if they generate a radical technological breakthrough. Thus, I identify paths to linkage formation for leading as well as peripheral firms. I test these arguments with longitudinal data on technical collaborative linkages in the global chemicals industry.* Copyright © 2000 John Wiley & Sons, Ltd.

Two broad classes of explanations have been offered to explain the formation of interfirm linkages or alliances between potential competitors.[1] One set of explanations has focused on the strategic or resource needs of firms. According to this perspective firms form linkages to obtain access to needed assets (Hagedoorn and Schakenraad, 1990; Harrigan, 1988; Nohria and Garcia-Pont, 1991), learn new skills (Baum, Calabrese, and Silverman, 2000; Hennart, 1988; Kogut, 1988; Powell, Koput, and Smith-Doerr, 1996), manage their dependence upon other firms (Pfeffer and Salancik, 1978), or maintain parity with competitors (Garcia-Pont and Nohria, 1999). Thus, linkage formation reflects firms' *inducements* or incentives to collaborate. A second set of explanations of alliance formation behavior has come from the structural sociological perspective and has argued that the patterns of observed interfirm linkages reflect the prior patterns of interfirm relationships (Gulati, 1995b, 1999; Gulati and Gargiulo, 1999; Walker, Kogut, and Shan, 1997). According to this view, a firm's ability to form new relationships is determined by the set of *opportunities* provided by its position in the prior network structure.

Although both perspectives provide insights into linkage formation behavior, neither approach provides a complete explanation. Researchers from the strategic needs or inducements perspective have often assumed, implicitly or explicitly, that the availability of opportunities is not a constraint and that the supply of linkage partners is infinitely elastic (Arora and Gambardella, 1990; Hagedoorn and Schakenraad, 1990). The validity of this assumption is debatable. Linkage formation inherently requires that not only must a firm be desirous of forming a linkage, it should also be attractive to potential partners (Kogut, Shan, and Walker, 1992; Shan, Walker, and Kogut, 1994). By failing to explicitly address the issue

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[1] I use the terms interfirm linkage, alliance, and interfirm relationship interchangeably to refer to collaborative arrangements between independent firms to share resources on an ongoing basis.

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of a firm's attractiveness to other firms the strategic needs perspective remains theoretically incomplete.

The findings of research on the benefits of interfirm linkages are relevant to this issue. Studies indicate that interfirm linkages help firms to develop and absorb technology (Ahuja, 1998; Harianto and Pennings, 1990; Powell *et al.*, 1996), withstand environmental shocks (Miner, Amburgey, and Stearns, 1990), and improve survival prospects and financial performance (Baum and Oliver, 1991; Baum *et al.*, 2000; Hagedoorn and Schakenraad, 1994; Mitchell and Singh, 1996; Rowley, Behrens, and Krackhardt, 2000; Singh and Mitchell, 1996; Zaheer and Zaheer, 1997). Finding these positive relationships between interfirm linkages and firm performance raises a natural question: if linkages are associated with these benefits then why do all firms *not use* linkages to improve their performance (Galaskiewicz and Zaheer, 1999; Masten, 1993)? One possible explanation of the observed variance on collaboration behavior is simply that the opportunities to collaborate are not equally available to all parties.

The social structural perspective recognizes the role of strategic inducements to collaborate, but focuses attention primarily on the sociological determinants of linkage formation opportunities (Gulati, 1995a, 1998; Gulati and Gargiulo, 1999; Kogut *et al.*, 1992; Walker *et al.*, 1997). Specifically, it argues that the structure of the existing interfirm linkage network influences the path of future relationship formation by affecting the set of linkage opportunities available to prospective collaborators. Although modeling the endogeneity of future linkage formation and relating it to current network structure, and recognizing the role of opportunities in linkage formation, are both significant accomplishments of this perspective, it suffers from two limitations. First, it does not explicitly address the possibility that there may be other determinants of the collaboration opportunities facing firms beyond social capital. Second, it leaves an important question unanswered. If linkage formation opportunities depend primarily on prior participation in the network, how can new actors who lack these relationships and the opportunities they embody ever form linkages or become central in networks?

In this paper I develop an integrative framework that explicitly recognizes the duality of the linkage-formation process and builds on both the strategic needs and social structural perspectives. I focus on the fact that linkages are formed only when actors with inducements to form linkages are successful in finding collaboration opportunities. Hence, I suggest that any explanation of linkage formation behavior must account for both the actor's inducements to form linkages and his/her opportunities to collaborate. In adopting this integrative perspective on alliance formation I build on recent research that has used a similar strategy (Eisenhardt and Schoonhoven, 1996).

The inducements-opportunities framework that I present in this paper extends research on linkage formation on three dimensions. First, I build on the inducements arguments by simultaneously considering the impact of different levels of inducements *and* opportunities on linkage formation, rather than only inducements. Second, I build on the social structural perspective by recognizing that a firm's opportunities may be determined by factors additional to and distinct from its social capital advantages and identify a firm's technical and commercial capital as two such factors. Finally, I describe a path to linkage formation that does not necessarily depend on prior levels of social, technical, or commercial capital and thus permits even new actors lacking in these advantages to obtain partners.

In the next section I develop the theory relating the three forms of capital to linkage formation inducements and opportunities. It is likely that the theoretical processes underlying linkage formation for vertical relationships will differ from those underlying horizontal relationships (Gulati and Lawrence, 1999). In this paper I restrict my theory and subsequent empirical work to explaining horizontal linkages. Further, following past research I make a distinction between collaborative arrangements that involve a technological component such as developing a new technology or sharing a manufacturing process vs. collaborative arrangements that are focused purely on sharing marketing assets or brand names (Hagedoorn and Schakenraad, 1994; Singh and Mitchell, 1996). Since the theoretical arguments explaining marketing based relationships may be different from those for technical relationships, for analytic clarity and focus I restrict my attention to the latter.

BACKGROUND AND THEORY DEVELOPMENT

The resource-based view of the firm suggests that firm behavior can be interpreted as a search for competitive advantage. Firms seek to obtain control over those factors of production that can provide them with a competitive edge over their closest rivals (Galaskiewicz and Zaheer, 1999; Wernerfelt, 1984). Factors that can provide such competitive advantages, *resources* in the parlance of this perspective, have three distinctive characteristics. First, they create value for the firm, i.e., they help firms to either reduce cost of inputs, or obtain greater prices for outputs (Barney, 1986). Second, they are often firm-specific in nature and are either unavailable outside the creating firm or suffer a diminution in their value if separated from the creating firm (Dierickx and Cool, 1989). Third, they are likely to be asset-stocks whose creation requires accumulation over time (Dierickx and Cool, 1989). Resources cannot be instantaneously developed.

A firm's *inducements* to form linkages can be related to its need for resources. Through interfirm linkages firms can obtain access to assets that create value, are not available for purchase in factor markets, and require time to build up. By collaborating with firms that have developed stocks of the relevant assets, and sharing those existing assets, firms can resolve the problem of accumulation of assets across time. Further, since the shared assets can be accessed without separating them from the original firm, the problem of tradability can also be bypassed. Thus, if a firm lacks competitive resources, it can use interfirm linkages to overcome this deficiency. The greater the firm's competitive resource deficiency and need to obtain the relevant resources, the greater its inducements to form linkages.[2]

A firm's linkage-formation *opportunities* are also likely to be related to its possession of resources. The number of potential partners that are willing to link with a firm is a function of the firm's attractiveness to other firms. A firm's attractiveness to potential partners in turn depends on the value that it can add to them. The most value that a firm can provide to its partners will occur when a firm can make available assets that are difficult for the partners to create on their own or obtain profitably from factor markets, i.e., when it can provide assets that have *resource* characteristics. The greater a firm's stock of resources, the greater the firm's attractiveness to partners, and the greater the firm's collaboration opportunities.

A firm's stocks of technical capital, commercial capital, and social capital represent three kinds of asset-stocks that meet the conditions to qualify as resources. Technical capital represents a firm's capabilities in creating new technology, products, and processes. Commercial capital represents the supporting or complementary assets that a firm needs to commercialize new technologies and obtain rents from them. Social capital represents the firm's prior relationships with other firms and provides it with information and status benefits. Although I examine the characteristics of these assets in greater detail in the hypotheses that follow, I note here that each of these asset-stocks adds value, is accumulated over time, and is difficult to trade across markets.

Technical capital, commercial capital, and the formation of technical linkages

A firm's attractiveness to potential partners and hence its opportunities to collaborate are likely to vary positively with its stocks of technical capital. Development of a knowledge-base or technological competence in a field is difficult, time-consuming, and expensive. Technological and market uncertainties combine to make technology development decisions difficult (Mitchell and Singh, 1992). Expensive equipment, skilled personnel and large investments with uncertain returns together imply that research is often a high-cost, uncertain-benefit, exercise. Further, for many technologies, participation in later stages of technological development is conditioned by knowledge accumulation through participation in previous stages (Dosi, 1988). A lengthy presence in the technology is therefore often necessary to develop significant technical capabilities.

Given this, only some firms can hope to acquire technical skills of a high order, and firms that fail to make substantial investments in the developmental stages of a technology may fail to

[2]Acquisitions represent another alternative to fulfill such deficiencies. However, if the needed resources are only part of a larger firm an acquisition may be an inefficient and relatively expensive way to obtain such resources. Further, acquisitions may entail greater sunk costs and rigidity relative to collaborative linkages.

develop a significant knowledge base in the technology. Further, they may find it progressively difficult and expensive to catch up later through internal development (Shan, 1990). Yet commercial necessity may force them to obtain such technological competencies, often within a short span of time. Firms then look to other firms that have made such commitments in the past and seek to learn from their accumulated competence (Mitchell and Singh, 1992).

In such circumstances the past innovative activities of firms serve as signals of their accumulated technical competence (Arora and Gambardella, 1990). Firms with a history of innovativeness can be regarded as technically competent (Podolny and Stuart, 1995; Stuart, 1998; Stuart, Hoang, and Hybels, 1999). Such firms are attractive to other firms who hope to acquire greater knowledge through partnerships with them rather than through partnerships with less accomplished firms (Baum *et al.*, 2000). Other things being equal, firms with a history of innovativeness should thus have many firms willing to partner with them. Conversely, firms that have little or no expertise in the technologies of an industry have little to offer to partners, at least with respect to technology. Such firms should find fewer willing and able partners. Thus, the opportunities to collaborate are likely to vary positively with the possession of higher levels of technical capital.

A firm's attractiveness to potential partners and hence its opportunities to collaborate are also likely to vary positively with its stocks of commercial capital. Converting technical innovations to products and services entails the development of manufacturing and marketing capabilities, and assets such as manufacturing facilities and service and distribution networks (Mitchell, 1989; Teece, 1986). Development of such supporting or complementary assets may require significant up-front investments and fixed costs (Teece, 1986). Further, the development of such assets may be associated with a significant gestation lag (Shan, 1990), and attempts to shorten the gestation period may induce time compression diseconomies (Dierickx and Cool, 1989; Mansfield, 1988). In the face of limited resources and technical and market uncertainty, firms lacking such assets may prefer to acquire access to them through interfirm linkages rather than through in-house development or acquisition (Mitchell and Singh, 1996; Shan, 1990). Possessing such assets can be the basis of a firm's attractiveness to partners who possess the technological capabilities to innovate but lack the supporting assets to commercialize the innovation (Teece, 1986). Other things being equal, firms possessing such assets are more attractive as partners than firms lacking such assets. Thus, a firm's stock of commercial capital is likely to have a positive impact on the linkage opportunities available to a firm.

In summary, the above arguments suggest that the possession of either technical or commercial capital can help a firm to become attractive in the linkage formation arena and be privy to linkage formation opportunities. However, the actual linkage formation behavior of firms must reflect not just the opportunities available to firms but also the inducements for them to form linkages. Firms that lack either the ability to invent new technologies or the wherewithal to commercialize them clearly have strong incentives to collaborate as collaboration can be the means to obtain access to the commercial or technical capital that they lack. Conversely, firms that are well endowed with both technical and commercial capital have relatively muted incentives to form linkages. Since such firms already possess high levels of both technical and commercial capital the marginal benefits provided by technical linkages are relatively small. However, in forming linkages such firms would have to share their knowledge or commercial assets with their competitors, possibly undermining their own competitive advantage and position in the industry (Mitchell and Singh, 1992). Further, such well-endowed firms may stand to learn much less from their partners than their partners can learn from them (Hamel, Doz, and Prahalad, 1989; Kale, Singh and Perlmutter, 1999; Khanna, Gulati, and Nohria, 1998). Thus, given the relatively limited benefits of collaboration and the relatively high competitive costs of forming linkages it is likely that firms that possess high levels of both technical and commercial capital will have low inducements to form linkages. Even though their high levels of endowments may make them attractive to many partners, their relatively low inducements will inhibit linkage formation. Combining the opportunity and inducement arguments suggests that even though higher technical or commercial capital individually fosters enhanced linkage formation by expanding the collaboration opportunities for the firm, the interaction of the two serves to reduce the inducements to collaborate. The above arguments suggest the following three hypotheses:

Hypothesis 1: The higher a firm's technical capital, the greater the number of linkages formed by the firm.

Hypothesis 2: The higher a firm's commercial capital, the greater the number of linkages formed by the firm.

Hypothesis 3: The interaction between technical and *commercial capital has a negative impact on linkage formation. The higher a firm's technical* and *commercial capital, the fewer the number of linkages formed by the firm.*

Social capital and linkage formation

Skills or material resources such as technical and commercial capital represent one set of factors influencing linkage formation. Social structural influences represent the other (Gulati, 1995b). Networks of existing ties between firms can facilitate the formation of subsequent linkages by providing both information and reputation benefits to well-connected firms (Gulati, 1995b, 1999). Such *network resources* represent a distinct form of capital—social capital—that is different from the technical and commercial capital described earlier (Gulati, 1999). Unlike technical and commercial capital which are both inherently necessary to develop and commercialize technology in most contexts, the role of social capital can vary from facilitative to substantive.

In its facilitative form social capital provides information on collaboration opportunities and signals the reliability of potential partners on the basis of their prior collaborative behavior (Gulati, 1995b, 1999). Social capital can also take on a more substantive role in certain contexts. In some industries the prevalence or dominance of a technical standard determines the subsequent competitive performance of firms. Being associated with the dominant technical standard can help a firm obtain legitimacy for its own products. In such circumstances being allied to the appropriate firms can itself be a necessary condition for the successful development and commercialization of a firm's technology, thus raising the exchange value of social capital in such industries (Galaskiewicz and Zaheer, 1999; Kogut, Shan and Walker, 1993). Eventually, whether the facilitative or the substantive role of social capital is more important is likely to depend on the industrial context. In industries where network externality and standards issues are critical it is likely that social capital itself will enjoy substantive importance; in other industries its role is likely to be more facilitative. In the current study the empirical context is the chemicals industry, where network externality issues are relatively unimportant. Accordingly, I focus on the facilitative role of social capital.

In the following paragraphs, I present the discussion relating the number of linkages formed by a firm to its social capital, or prior embeddedness in the industry. I suggest that the relationship between linkage formation and social capital is nonlinear. Highly embedded firms or least embedded firms will form fewer linkages than moderately embedded firms.[3]

Embeddedness exerts two contradictory influences on a firm's incentives to form linkages. On the one hand a history of dense and extended interfirm linkages provides a firm with expertise in managing such linkages (Anand and Khanna, 2000; Gulati, 1993; Westney, 1988). Organizational arrangements to coordinate linkages can be devised and the tasks of alliance management and related activities can be institutionalized within the organization's regular routines (Westney, 1988). Extended experience with linkages also reduces a firm's uncertainty about the process and reduces inertial barriers to linkage formation. Finally, embeddedness in the network serves to provide

[3]Although I theorize about technical and commercial capital interactively, I theorize about social capital separately. The importance of the facilitative rather than substantive role of social capital in the context of the chemicals industry explains why I do not develop interaction hypotheses for social capital. In the chemicals industry technical and commercial capital are both relatively more necessary to develop a technology and appropriate the rent from it. Social capital can facilitate this process, but it does not necessarily have to exist for this process to be consummated. Thus, while technical and commercial capital are deeply linked in the technology development and commercialization process, the linkage between social capital and these two forms of capital is much weaker. Accordingly, I do not develop an argument that firms need social capital in the same way that they need technical and commercial capital.

information on the capabilities and likely behavior of many potential partners. This further alleviates the risk associated with linkage formation and helps to increase the firm's willingness to form linkages.

Against these positive impacts of increased embeddedness lies the negative influence of saturation (Kogut *et al.*, 1992). Every linkage that embeds a firm more deeply in the industry network also places a strain on its management and absorptive capacity. Beyond a point the learning and risk reduction benefits of embeddedness diminish. However, the costs of maintaining linkages increase significantly as not only are firms required to manage individual links, but they are also required to coordinate management effort across links (Harrigan, 1985). Further, there is a natural limit to the time and effort that any firm can devote to managing its linkages. Given this, highly embedded firms may be reluctant to form further new linkages. Thus, the incentives to form linkages are likely to increase with embeddedness initially but beyond a point embeddedness will have a negative impact on the desire to form new linkages.

Embeddedness will positively impact a firm's opportunities to form linkages through at least three mechanisms. First, highly embedded firms can obtain information about linkage formation opportunities from their partners and their partner's partners (Gulati, 1995b). Firms seeking collaboration partners for new projects may discuss their needs with their partners. These partners can relay this information to other firms they are currently partnering with.

Second, the embeddedness of firms itself serves as a signal of their reliability. Partnering with many firms reinforces their reputation as desirable collaborators. Further, their partners can serve as sources of information about their capabilities and behavior (Gulati, 1993). For other firms, transacting with highly embedded firms on whom information is available is less risky than transacting with firms whose collaborative behavior is unknown.

Third, the embeddedness of firms serves as a signal of their access to other highly embedded actors (Mizruchi *et al.*, 1986). Highly embedded firms are resources not just in themselves but also as a means to link with other prominent actors. Linking with such central firms can enable partners to enjoy reflected benefits (Mizruchi *et al.*, 1986). Thus, embeddedness by itself adds to a firm's attractiveness as a partner.

A firm's observed linkage behavior will reflect the joint effect of its incentives to link and the linkage opportunities open to it. At low levels of embeddedness a firm's limited attractiveness as a partner will restrict the number of linkage opportunities available to it. Even though it may be desirous of forming more links the lack of available opportunities will serve as a constraint and the observed level of new linkages will be low. At high levels of embeddedness firms will enjoy many opportunities to link. However, the marginal benefits of forming new linkages will be low and the marginal costs of additional links will be relatively high. Therefore, the willingness to form new linkages will be low. Again, few new links will be formed. Firms at intermediate levels of embeddedness will have both high inducements and high opportunities to form new links. Such firms will be most active in the linkage formation process. This argument suggests the following hypothesis:

> *Hypothesis 4: The number of new linkages established by a firm in any year will be curvilinearly related to its level of social capital. Highly embedded firms and least embedded firms will form few linkages relative to moderately embedded firms.*

The three forms of resources identified so far—technical, commercial, and social capital—all highlight the advantages of an established presence in the industry. The development of technical skills, supporting assets, or interfirm relationships all entail significant commitments of resources over extended periods of time. This temporal characteristic of these advantages suggests that the ability to form linkages is likely to be an incumbency prerogative: firms with established histories of technical, commercial, and social advantages enjoy superior opportunities to form linkages and are likely to occupy central positions in the industry network; new entrants are likely to be relegated to the periphery of the industry.

This characterization is, however, theoretically unappealing, empirically inaccurate, and normatively concerning. Theoretically, this characterization limits our ability to explain the formation of collaborative linkages by firms lacking in these three forms of capital. Empirically, it appears unlikely that industrial networks are characterized by such levels of core–periphery stability with only established actors being able to form relationships (Madhavan, Koka, and Prescott, 1998). Normatively, a network that has such a rigid structure may be undesirable as it could impede the emergence of novel actors and ideas.

Thus, to complete the story of differential opportunities in the linkage formation arena it is also important to identify a path by which firms that lack the above incumbency advantages may still enjoy the benefits of collaboration. In the discussion that follows I present one possible path to linkage formation opportunities that does not necessarily rely upon past commitments and can be used even by firms lacking these stocks of capital to break the cycle of incumbent dominance: the creation of a radical technological breakthrough. I examine this possibility next.

Important inventions and linkage formation

The discussion leading to Hypothesis 1 relating past innovativeness to linkage formation focused on one aspect of technological progress: its cumulative, path-dependent nature (Dosi, 1988; Nelson and Winter, 1982; Podolny and Stuart, 1995). Technological progress is often an incremental process, with knowledge building upon past knowledge and experience in an additive fashion, resulting in the emergence of discernible technology trajectories (Dosi, 1988; Sahal, 1985). Firms that participate in previous generations of a technology are advantaged *vis-à-vis* later entrants and firm-specific knowledge bases or competencies are a significant component of a firm's competitive position (Dosi, 1988).

Yet, technological development can also be radical, marked by significant discontinuities rather than smooth progress along 'innovation avenues' (Sahal, 1985; Tushman and Anderson, 1986). Technological trajectories mark paths of sustained technological innovation (Methe, 1992). Technoeconomic paradigms associated with each trajectory provide both a basis for selecting which of the many technical problems will be addressed, as also the heuristics, and approaches that will be used to identify solutions to the selected problems (Dosi, 1988). However, new innovative combinations may emerge that upset the orderly evolution imposed by a technoeconomic paradigm (Ayres, 1994). By using different sets of heuristics and approaches, or possibly by addressing different problems, or defining problems differently, firms may introduce alternative configurations that satisfy needs in completely novel ways or improve performance by orders of magnitude.

If such breakthroughs emanate from incumbents, they serve to build the competence base and assets of such firms and provide greater strength to their competitive position and attractiveness (Tushman and Anderson, 1986). Alternately, if such breakthroughs occur outside the circle of dominant firms they represent a window of opportunity for the hitherto underprivileged firm that is responsible for the breakthrough. Fostering such breakthroughs increases a firm's attractiveness to other firms who may be interested in building on the novel technical development or sharing in its exploitation. Thus, authorship of critical, path-breaking ideas is likely to be associated with a greater attractiveness to other partners and potentially, greater opportunities to form linkages. For firms lacking in technical, commercial, and social capital, this effect is likely to be especially strong as such firms have no other currency to use in attracting potential partners in the linkage formation arena.

Such important or radical inventions may also affect a firm's inducements to form linkages. Firms that lack the accumulated stocks of capital required to further develop radical inventions will have significantly increased motivations to form linkages as obtaining a commercial return from their invention may otherwise not be possible. However, firms that are better endowed with technical, commercial, and social capital may be able to develop the invention without forming new linkages. It is more likely that breakthrough inventions will enhance linkage formation inducements, most notably for poorly endowed firms. Thus, from both inducement and opportunity perspectives, Important Inventions are likely to increase linkage formation for poorly endowed firms to a greater extent than for better endowed firms. Therefore, I suggest:[4]

Hypothesis 5: The greater the number of

[4] I would like to acknowledge the contribution of an anonymous reviewer who suggested that the effect of such important inventions is likely to be greatest for firms lacking in all forms of capital.

Important Inventions created by firms lacking technical, commercial, and social capital, the higher the number of linkages formed by such firms in subsequent years.

The above hypotheses summarize the effects of four critical sets of influences on linkage formation. Hypotheses 1 and 2 focus on the role of accumulated technical competencies and commercial capital in providing differential opportunities to firms. Hypothesis 3 focuses on the role of technical and commercial capital as sources of variation in the inducements to form linkages. Hypothesis 4 focuses on the role of social capital in determining firms' collaboration opportunities and inducements.

All these hypotheses draw attention to the benefits of tenure. Yet the past does not necessarily predict the future. Hypothesis 5 provides a means of reconciling these advantages of prior experience in the industry with an empirical reality: new firms do emerge and sometimes dominate industries. By relating a firm's collaboration opportunities to its ownership of path-breaking ideas it provides a mechanism for a firm lacking in the first three sets of advantages to still form linkages. In Table 1 I provide a summary of these predictions.

METHODS AND MEASURES

Data

I tested the hypotheses on a longitudinal data set comprising the linkage activities of 97 leading firms from the global chemicals industry over the period 1979–91. Sampling on the leading firms in the industry was deemed necessary to ensure the availability and reliability of data. Information on the key variable, collaborative linkages, is extremely difficult to obtain for small firms over an extended time period. Past network studies on alliances have used a similar strategy of focusing on the leading firms in an industry (Gulati, 1995a, 1995b). It is noteworthy, however, that examining 97 firms within the industry leads to a sample characterized by considerable variance on the key variables, as discussed in the Results section.

The leading firms in the chemicals industry were identified from lists that are published annually by trade journals such as *Chemical Week* and *C&E News*. To avoid sampling on the dependent variable I collected information on all firms identified from the lists without regard for whether or not they had formed linkages in a given year (Gulati, 1999). In these published lists subsidiaries were often listed separately from parent firms. From an original sample of approximately 120 firms, after including subsidiaries with parent firms a sample of 107 firms remained. For 10 of these firms data could not be reliably obtained and consequently they were dropped from the analysis. The remaining firms include all the key firms in the industry over the study period. The panel is unbalanced as some of the firms were acquired by other firms or restructured in a fashion that made comparison difficult beyond a particular year. A full list of the sample firms is available from the author.

I obtained data on collaboration through detailed archival research on the chemicals and materials sector. Three main types of data sources were used to identify linkage activity: (1) electromagnetic data bases, including both general business news media such as the Dow Jones News Retrieval Text Index as well as sector-specific data bases such as Metadex, (2) general business print media such as the Frost and Sullivan Predicasts Index (United States, International, and Europe), as well as industry-specific publications such as *Chemical Week*, and *Plastics Technology*, and (3) government publications and consultant reports for the chemicals industry. Every attempt was made to ensure that the data collection was comprehensive in its coverage of the sampled firms' linkage activities. The data-collection and coding exercise for the entire data set involved studying over 130,000 electronic news stories and dozens of text works and was completed over almost 2 years. The sample of 97 firms was involved in 469 collaborations among themselves over the period 1979–91. This total included 178 research agreements and 291 joint ventures.

To measure a firm's embeddedness at any point in time ideally one should have information on both the formation and the dissolution of linkages. In previous studies lack of availability of data on linkage dissolution has meant that no distinction has usually been made between linkages formed by the firm and the linkages maintained by the firm at any point in time. In this research an effort was made to address this gap. Accordingly, an attempt was made to record dissolution or continuity information for all linkages. This also

Table 1. List of variables and predictions

Variable name	Hypothesis	Predicted sign
Technical Links Formed$_{it}$ (Total)		Dep Var
Technical Links Formed$_{it}$ (Joint Ventures)		Dep Var
Technical Links Formed$_{it}$ (Research Agreements)		Dep Var
Technical Capital (Patents, '00's)$_{it-1}$	1	+
Commercial Capital (Assets, \$bn)$_{it-1}$	2	+
Technical *Commercial$_{it-1}$	3	−
Social Capital (Prior Degree Centrality)$_{it-1}$	4	+
Social Capital (Prior Degree Centrality) Sqr$_{it-1}$	4	−
Capital-Poor Firm *Important Inventions$_{it-1}$	5	+
Capital-Poor Firm *Important Inventions$_{it-2}$	5	+
Capital-Poor Firm *Important Inventions$_{it-3}$	5	+
Capital-Poor Firm *Important Inventions$_{it-4}$	5	+
Capital-Poor Firm		NP
Important Inventions$_{it-1}$		NP
Important Inventions$_{it-2}$		NP
Important Inventions$_{it-3}$		NP
Important Inventions$_{it-4}$		NP
Marketing Linkages$_{it-1}$		NP
Debt/Equity$_{it-1}$		NP
Current Ratio$_{it-1}$		NP
Return on Assets$_{it-1}$		NP
Diversification (Entropy)$_{it-1}$		NP

NP = no prediction.

helped in ensuring that linkages that were announced but subsequently did not materialize were identified and removed from the data.

Although the effort to obtain dissolution data entailed significant inputs on time and energy it met with mixed results. For the joint ventures in the sample the exercise was quite successful. For 194 of the 291 joint ventures, I was able to establish either the date of dissolution or the survival of the joint venture until beyond 1991, the concluding year of this study. For many of the remaining joint ventures I was able to establish continuity of operations until some data between date of founding and 1991. This occurred when the last information available about the joint venture dated prior to 1991 but did not refer to dissolution activity. I treated all joint ventures for which I did not have a record of dissolution as continuing to exist until 1991 for two reasons. First, my success at identifying dissolutions in the majority of cases led me to believe that at least for this sample of firms joint venture dissolution tends to be reported. Hence, the absence of a confirming report of dissolution was best interpreted as an indicator of continuing operations. Second, in many of the cases trade and news reports indicated ongoing operations or specific activities at these joint ventures for several years after founding. The fact that other news about these ventures was being reported made it seem likely that their dissolution would also be reported. Assuming continuity in the absence of news of dissolution seemed to be the more accurate assumption to make about these ventures.

The situation was, however, quite different for research agreements and technology development and sharing arrangements not involving the formation of a separate entity. For such agreements dissolution was coded based on tenure specified in the formation announcement or on formal notice of conclusion of the research, where available. For long-term (multiyear) or general programs of research one of the two above conditions was often the case. However, in the majority of cases I was unable to establish formal dissolutions. In such cases the agreement was presumed to exist until the later of the following: the last year in which it was documented, or the year after the year it was founded. The assumption of a short life for such agreements relative to joint ventures that is implicit in the above treatment is consistent with the very specific and short-term nature of their objectives in most cases. For research agreements there were also cases when the existence or ongoing activities of the collaboration were discussed but the founding of the collaboration itself was not reported or indicated. In such cases the collaboration was treated as having been founded in the year immediately prior to the year in which it was first documented. In the statistical analysis I also used several alternate assumptions that I briefly report upon in the Results section of the paper.

Financial data for the firms were obtained from Compustat, Worldscope, trade publications, company annual reports, and *Japan Company Handbooks* and *Daiwa Institute Research Guides*. For all firms financial data were converted to constant (1985) U.S. dollars. All independent variables were lagged by 1 year.

Variable definition and operationalization

Dependent variable

Technical Links Formed: This variable is defined as the count of new technical collaborative linkages formed by a firm with other firms in the sample in any year. Only collaborations that involved a technical component were included in this variable. Agreements that entailed only marketing or distribution arrangements were included in a separate variable described below. Within technical collaborations two distinct forms of activity were identified: joint ventures, in which the collaborators set up a distinct organizational entity, and joint development and technology-sharing agreements, in which the firms collaborated but did not set up a distinct organization for this purpose. Both joint ventures and collaborative agreements were included in computing the **Technical Links Formed** variable. However, all analyses were also repeated using the variables **Technical Links Formed (Joint Ventures)** and **Technical Links Formed (Technology Agreements)** separately.

Independent variables

Technical Capital (Patents)$_{it-1}$: I used total number of chemicals patents obtained by a firm in the 4 prior years as my indicator of a firm's cumulated technical capital. Patents represent externally validated measures of innovative success and can therefore be interpreted as signals of technological competence (Narin, Noma, and Perry, 1987). Past research also establishes that the patenting record of firms is closely related to their stature in the technical arena (Narin *et al.*, 1987; Trajtenberg, 1990).

A 4-year window was chosen because the attractiveness of a firm is contingent upon its viable stocks of technical knowledge. In a technologically vibrant industrial sector 4 years probably represents an appropriate time frame for currency of a firm's knowledge base. Variables using 3- and 5-year time windows were also computed to check for the sensitivity of this measurement to the choice of time period. These new variables were correlated with the original 4-year based variable with $r > 0.95$. This suggested that the variable was not unduly sensitive to the time window chosen for measurement. The choice of a 3- to 5-year time frame for measuring technical capital is also consistent with studies of R&D depreciation (Griliches, 1984) and other technology studies (Stuart and Podolny, 1996).

I used patent data from the U.S. Patents Database for all firms, including firms that are headquartered outside the United States. This was necessary to maintain consistency, reliability, and comparability, as patenting systems across nations differ in their application of standards, system of granting patents, and value of protection granted (Basberg, 1987; Griliches, 1990). The United States represents one of the largest markets for chemicals, and firms desirous of commercializing their inventions would most likely patent in the United States if they were to patent anywhere at all. Prior research using patent data on international samples has followed a similar strategy of using U.S. patent data for international firms (Patel and Pavitt, 1997; Stuart and Podolny, 1996). Prior studies of the global chemicals industry have also used U.S. patent data for all firms, including international firms (Achilladelis, Schwarzkopf, and Cines, 1990).

I obtained patent counts for each firm through the following procedure. First, for each firm in the sample a list of all its divisions, subsidiaries, and joint ventures was prepared using *Who Owns Whom* (United States, United Kingdom and Ireland, Continental Europe, and Asia editions) and the *Directory of Corporate Affiliations*. Thereafter, each firm's history was traced through the study period to account for any name changes and reorganizations and to obtain information on the timings of events such as the founding and dissolution of joint ventures. This master list of firm names was used to identify all patents issued to the sample firms.

The list of chemicals patents owned by these firms was derived from the above master list using the technology class information on the patents. The U.S. patent system classifies the technology domain into 400 broad classes and several hundred thousand subclasses nested within the classes. Each patent is assigned to a primary technology class by patent examiners. The *Patent Manual* was used to identify the technology classes corresponding to chemicals. Using the identified technology classes the chemicals patents of the sample firms were separated from other patents obtained by them.

Commercial Capital (Assets)$_{it-1}$: I used the firm's assets in the chemicals business as a measure of the firm's commercial capital. To compute this I multiplied the assets owned by the firm by the proportion of its total sales turnover that was drawn from the chemicals business. To ensure the robustness of results I also used the sum of the previous 5 years' chemicals sales as an alternate measure of commercial capital.

Social Capital (Prior Degree Centrality)$_{it-1}$: To measure a firm's prior embeddedness in the industry network I used the firm's degree centrality (number of linkages) in the prior industry network. I constructed the industry networks for each year from 1982 to 1990 using information on all technical linkages maintained by the firm with the other 96 firms in the sample in that year. Since some linkages from previous years are likely already to be existing at the start of the study period (1982) I obtained data on all collaboration activity in 1979, 1980 and 1981 in addition to the data on linkages in the study period, 1982–90. Using the data from 1979 to 1981 I constructed the 1982 network to include all linkages formed in the previous 3 years that had not yet been dissolved as of 1982. As noted earlier, if I was unable to identify the dissolution of a joint venture I treated it as continuing to exist, while all research agreements were presumed to end in the year following their commencement unless I was able to identify their continued existence. I also reconstructed the networks under several different assumptions, including cumulating all links over time (the approach used by Gulati, 1995b and Singh, 1997), and using a 5-year moving window. As I report in the Results section, the alternate measures produce similar results.

Capital-Poor Firms: I identified capital-poor firms in any year as those that were below the median on all three forms of capital (technical, commercial, and social) for that year. Hypothesis 5 suggests that the interaction between this variable and the Important Inventions variable described next should be positively associated with linkage formation.

Important Inventions: I used patent citation counts to identify important inventions. Several studies have shown that patent citation counts are important indicators of the technical importance of an innovation (Albert *et al.*, 1991; Narin *et al.*, 1987; Trajtenberg, 1990). Further, highly cited patents represent critical or path-breaking inventions (Trajtenberg, 1990). For each successful chemical patent application for the capital-poor firms between the years 1979 and 1990, I computed the number of citations received by the patent after excluding self-citations. For every year I sorted the patents applied for in that year on the basis of their citation weights and identified the top one-half per cent of patents for that year as key patents. I then took the total *number* of such key patents for a given year as the value of the firm's Important Inventions for that year. Thus, a value of 2 for Important Inventions for a firm in 1987 indicates that if all chemicals patents applied for in 1987 by the sample firms were weighted by the citations received by them, and the top one-half percentile of these patents was selected, then the firm in question was the creator of two of these patents. This procedure ensures that each patent is compared in its importance only to other patents of the same year. Since the duration for which a patent is at risk of being cited varies for patents of different vintages, it is important to compare patents only with their own cohort. A similar procedure has been used in past research (Trajtenberg, 1990).

Important Inventions*Capital-Poor Firms: This variable is the interaction of the previous two variables. Hypothesis 5 predicts a positive impact of this variable on linkage formation.

Controls

I also included a number of control variables that may be alternate explanations for observed linkage formation behavior. **Debt/equity** measures the leverage characteristics of a firm and controls for financial motivations driving linkage formation behavior. **Current Ratio** measures the ratio of current assets to current liabilities and controls for financial liquidity or solvency imperatives that may be driving firms to collaborate. Following prior research (Gulati, 1999) **Return on Assets** is included as a measure of firm financial performance that might affect linkage formation behavior. **Diversification (Entropy)** is included as a control for the possible effects of diversification. The following formula was used to calculate **Diversification (Entropy)**: $=\Sigma P_j \times \ln\ (1/P_j)$, where P_j is defined as the percentage of firm sales in segment j and $\ln(1/P)$ is the weight for each segment j (Palepu, 1985). **Marketing Linkages** measures the cumulative number of marketing linkages formed by the firm and is included as a control for the firm's access to marketing collaborative relationships. I also included year and nation dummies in all models to account for any period-specific or nation-specific influences on the linkage formation process. I do not make any predictions on the effects of the control variables. Table 1 provides a complete list of all variables.

Model estimation and econometric issues

Model specification

I used a Poisson regression approach to test the above hypotheses. The dependent variable, number of links formed in a year, is a 'count' variable, which takes only discrete nonnegative integer values, and possibly has a large number of zero values. I used the following specification for the expected number of linkages.

$$E(L_{it}/X_{it-1}) = e^{X_{it-1}\beta} \tag{1}$$

where L_{it} is the number of linkages formed by firm i in year t, and X_{it-1} is a vector of regressors affecting the mean of L_{it}.

The Important Inventions variable presents a special econometric problem. Unlike the constructs of technical, commercial, and social capital, which are essentially cumulative in nature or change slowly across time, a path-breaking invention is a relatively discrete event. Further, although a path-breaking invention occurs at a discrete point in time its existence and importance may become known and understood only across several periods of time. Knowledge of the invention has to diffuse to potential collaborators and they have to understand its implications and importance before being able to initiate collaborative activity. Theory presents no significant guidance to the length of this lag between the generation of a key invention and the response of potential collaborators beyond indicating that the lag is likely to be of a moderate length, as ideas are likely to age and become less relevant as the technology progresses.

Distributed lag analysis is a technique that provides a means of assessing the impact of a change in an independent variable that is distributed over the values of the dependent variable for several future periods, rather than felt entirely at a single point in time (Judge *et al.*, 1988). Since the impact of an important invention is likely to be felt over a number of years, rather than entirely in any one year, I used a distributed lag approach to model this variable. To capture the lag effects, the one-period, two-period, three-period, and four-period lagged values of the Important Inventions variables were included as covariates in the above model. These distributed lag effects test the impact of an Important Patent for up to 4 years after the year the patent was originally applied for. Thus, illustratively speaking, in these models a firm's linkage formation behavior in 1986 is potentially influenced by its Important Inventions in 1982, 1983, 1984, and 1985.

The regression coefficients on the distributed lags can be summed to obtain the *total* impact of Important Inventions across time (Gujarati, 1988). The total impact of an Important Invention is likely to be distributed over several periods following its creation. Further, it is possible that the effect in any one period is relatively small and may not be statistically significant. However, summing across several periods may enable us to distinguish this impact more clearly. Since the variances and covariances of the individual lag coefficients are available from the regression output the variance of the summed coefficient can also be calculated. The summed coefficient can then be used for hypothesis testing. For instance, the hypothesis that the total impact of Important Inventions summed across all years is zero can be tested by computing the following Wald statistic and checking whether it is statistically significant at the desired confidence level:

$$W = (\beta_1 + \beta_2 + \beta_3 + \beta_4)^2 / \text{Variance}\ (\beta_1 + \beta_2 + \beta_3 + \beta_4)$$

where the β_i's are the regression coefficients for the the *i*th period lagged Important Inventions variable, and, W~chi-square with 1 degree of freedom.[5] The variance for the summed coefficients can be computed using the following relation (Judge *et al.*, 1988):

$$\begin{aligned} &\text{Variance}\ (\beta_1 + \beta_2 + \beta_3 + \beta_4) = \\ &[\text{Var}(\beta_1) + \text{Var}(\beta_2) + \text{Var}(\beta_3) + \text{Var}(\beta_4) \\ &+2\text{Cov}(\beta_1\beta_2) + 2\text{Cov}(\beta_1\beta_3) + 2\text{Cov}(\beta_1\beta_4) \\ &+2\ \text{Cov}(\beta_2\beta_3) + 2\text{Cov}(\beta_2\beta_4) + 2\text{Cov}(\beta_3\beta_4)] \end{aligned} \qquad (2)$$

Overdispersion and serial correlation are two possible problems with using Poisson regression in the context of panel data. Accordingly, I conducted tests to assess overdispersion (Cameron and Trivedi, 1986) and serial correlation (Hausman, Hall, and Griliches, 1984) for the basic Poisson specification. The tests for overdispersion indicated no overdispersion in the residuals. To assess the degree of serial correlation I constructed the period-by-period correlation matrix of the standardized Poisson residuals (Hausman *et al.*, 1984). The off-diagonal elements of this matrix indicate the degree of correlation between residuals of the same firm from different periods. The average value of all off-diagonal elements of this matrix (0.025) was not statistically significantly different from zero, indicating that serial correlation was not a problem even with the basic Poisson specification.

RESULTS

Table 2 presents descriptive statistics and correlations for all variables used in the study. The descriptive statistics indicate that the firms are characterized by significant diversity on key variables such as Technical Capital (sum of past 4 years' patents ranges from 0 to 1754), Commercial Capital (assets range from \$25 million to almost \$27 billion in constant prices), Social Capital (links range from 0 to 34) and Important Inventions (0 to 7). Another characterization of the range covered by the sample is provided by noting that the ratio of the highest value in the sample to the tenth percentile value is 134 for Technical Capital and almost 98 for Commercial Capital. Thus, even though the sample consists of the leading firms in the chemicals industry the inclusion of 97 firms ensures that there is considerable variance on almost all dimensions of the data.

The correlation matrix indicates moderate to high correlations between the hypothesized effect variables and the dependent variable ranging from a correlation of 0.32 (between Technical Capital and Links Formed$_{it}$) to 0.46 (between Social Capital$_{it-1}$ and Links Formed$_{it}$). The hypothesized effect variables are also correlated amongst themselves, with the highest correlation being between Technical Capital and Commercial Capital (0.82) and lesser correlations between Technical Capital and Important Inventions (0.46 to 0.56), Social Capital and Commercial Capital (0.47), and Social Capital and Technical Capital (0.29). Although coefficient estimates remain unbiased under multicollinearity, high correlations between the independent variables can lead to the inflation of standard errors and the false rejection of hypotheses (Greene, 1995; Judge *et al.*, 1988). However, the subsequent data analysis indicated that this was not a problem in the current context.

Table 3 presents the results of the Poisson regression analysis. Variables reflecting the hypothesized effects were entered into the regression individually and likelihood ratio tests are reported for all models. Model 1 presents the base model and includes only the control variables. All estimated models include 9 Year and 12 Nation dummies. The results on these dummy variables are not presented in Tables 3 and 4 owing to space constraints, and are available directly from the author. Models 2 through 4 include the hypothesized effect variables, Technical Capital, Commercial Capital, and the interaction between Technical and Commercial Capital, entered sequentially. Model 5 includes the Social Capital variable with its square term.

[5] Since the square root of the chi-square distribution with one degree of freedom is identical to the Student's t distribution, this hypothesis test can also be conducted by taking the square root of the W statistic and treating it as a t value. This makes the results on this variable comparable to all other regression coefficients.

Table 2. Descriptive statistics and correlation matrix for all variables

		Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Technical Links Formed$_{it}$ (Total)	0.76	1.06	0.00	8.00	1.00	0.78	0.75	0.32	0.39	0.32	0.46	0.41	−0.03	−0.01	0.00	−0.01	−0.27	0.15	0.24	0.14	0.16	0.32	0.03	−0.09	−0.04	0.16
2	Technical Links Formed$_{it}$ (Joint Ventures)	0.40	0.71	0.00	6.00	0.78	1.00	0.17	0.28	0.34	0.29	0.38	0.35	−0.01	0.01	−0.02	−0.02	−0.21	0.11	0.21	0.13	0.13	0.26	0.02	−0.02	0.01	0.15
3	Technical Links Formed$_{it}$ (Research Agreements)	0.36	0.67	0.00	5.00	0.75	0.17	1.00	0.20	0.24	0.19	0.32	0.28	−0.03	−0.02	0.02	−0.03	−0.20	0.12	0.16	0.08	0.11	0.23	0.02	−0.11	−0.07	0.10
4	Technical Capital (Patents,'00's)$_{it-1}$	1.86	3.00	0.00	17.54	0.32	0.28	0.20	1.00	0.82	0.88	0.29	0.21	−0.02	−0.03	−0.03	−0.03	−0.32	0.56	0.53	0.49	0.46	0.20	−0.17	0.22	0.14	0.39
5	Commercial Capital (Assets, $bn)$_{it-1}$	2.51	3.66	0.03	26.73	0.39	0.34	0.24	0.82	1.00	0.90	0.47	0.39	−0.03	−0.03	−0.03	−0.03	−0.34	0.53	0.50	0.47	0.43	0.23	−0.08	0.11	0.10	0.39
6	Technical *Commercial$_{it-1}$	13.72	44.26	0.00	438.59	0.32	0.29	0.19	0.88	0.90	1.00	0.32	0.26	−0.02	−0.02	−0.02	−0.02	−0.19	0.58	0.52	0.49	0.43	0.14	−0.12	0.19	0.12	0.35
7	Social Capital (Prior Degree Centrality)$_{it-1}$	5.20	5.34	0.00	34.00	0.46	0.38	0.32	0.29	0.47	0.32	1.00	0.91	−0.04	−0.05	−0.03	−0.04	−0.45	0.17	0.17	0.18	0.17	0.48	0.06	−0.19	−0.07	0.18
8	Social Capital (Prior Degree Centrality) Sqr$_{it-1}$	55.53	121.92	0.00	1156.0	0.41	0.35	0.28	0.21	0.39	0.26	0.91	1.00	−0.02	−0.03	−0.03	−0.02	−0.26	0.12	0.13	0.15	0.13	0.37	0.02	−0.12	−0.05	0.12
9	Capital-Poor Firm * Important Inventions$_{it-1}$	0.00	0.08	0.00	2.00	−0.03	−0.01	−0.03	−0.02	−0.03	−0.02	−0.04	−0.02	1.00	0.00	0.00	0.00	0.09	0.10	−0.02	−0.02	−0.02	−0.04	0.00	−0.03	0.01	−0.05
10	Capital-Poor Firm * Important Inventions$_{it-2}$	0.01	0.10	0.00	2.00	−0.01	0.01	−0.02	−0.03	−0.03	−0.02	−0.05	−0.03	0.00	1.00	0.00	0.00	0.12	−0.02	0.12	−0.02	−0.03	−0.05	−0.01	−0.03	−0.01	−0.05
11	Capital-Poor Firm * Important Inventions$_{it-3}$	0.01	0.09	0.00	2.00	0.00	−0.02	0.02	−0.03	−0.03	−0.02	−0.03	−0.03	0.00	0.00	1.00	0.00	0.11	−0.02	−0.02	0.12	−0.02	−0.04	−0.02	−0.03	−0.02	−0.06
12	Capital-Poor Firm * Important Inventions$_{it-4}$	0.00	0.06	0.00	1.00	−0.01	0.02	−0.03	−0.03	−0.03	−0.02	−0.04	−0.02	0.00	0.00	0.00	1.00	0.10	−0.02	−0.02	−0.02	0.08	−0.04	−0.02	0.02	0.03	−0.09
13	Capital-Poor Firm	0.27	0.44	0.00	1.00	−0.27	−0.21	−0.20	−0.32	−0.34	−0.19	−0.45	−0.26	0.09	0.12	0.11	0.10	1.00	−0.18	−0.18	−0.18	−0.20	−0.31	−0.07	0.17	−0.04	−0.18
14	Important Inventions$_{it-1}$	0.23	0.71	0.00	7.00	0.15	0.11	0.12	0.56	0.53	0.58	0.17	0.12	0.10	−0.02	−0.02	−0.02	−0.18	1.00	0.46	0.48	0.36	0.16	−0.09	0.01	0.05	0.18
15	Important Inventions$_{it-2}$	0.22	0.66	0.00	6.00	0.24	0.21	0.16	0.53	0.50	0.52	0.17	0.13	−0.02	0.12	−0.02	−0.02	−0.18	0.46	1.00	0.38	0.45	0.14	−0.10	0.02	0.04	0.19
16	Important Inventions$_{it-3}$	0.21	0.63	0.00	6.00	0.14	0.13	0.08	0.49	0.47	0.49	0.18	0.15	−0.02	−0.02	0.12	−0.02	−0.18	0.48	0.38	1.00	0.28	0.12	−0.09	0.01	0.02	0.19
17	Important Inventions$_{it-4}$	0.21	0.60	0.00	6.00	0.16	0.13	0.11	0.46	0.43	0.43	0.17	0.13	−0.02	−0.03	−0.02	0.08	−0.20	0.36	0.45	0.28	1.00	0.10	−0.09	0.03	0.08	0.17
18	Marketing Linkages$_{it-1}$	1.02	1.38	0.00	9.00	0.32	0.26	0.23	0.20	0.23	0.14	0.48	0.37	−0.04	−0.05	−0.04	−0.04	−0.31	0.16	0.14	0.12	0.10	1.00	0.08	−0.19	−0.01	0.14
19	Debt/Equity$_{it-1}$	3.35	4.02	0.36	40.00	0.03	0.02	0.02	−0.17	−0.08	−0.12	0.06	0.02	0.00	−0.01	−0.02	−0.02	−0.07	−0.09	−0.10	−0.09	−0.09	0.08	1.00	−0.32	−0.44	0.01
20	Current Ratio$_{it-1}$	1.58	0.62	0.50	5.08	−0.09	−0.02	−0.11	0.22	0.11	0.19	−0.19	−0.12	−0.03	−0.03	−0.03	0.02	0.17	0.01	0.02	0.01	0.03	−0.19	−0.32	1.00	0.38	0.01
21	Return on Assets$_{it-1}$	0.04	0.03	−0.13	0.24	−0.04	0.01	−0.07	0.14	0.10	0.12	−0.07	−0.05	0.01	−0.01	−0.02	0.03	−0.04	0.05	0.04	0.02	0.08	−0.01	−0.44	0.38	1.00	−0.11
22	Diversification (Entropy)$_{it-1}$	1.30	0.33	0.20	2.19	0.16	0.15	0.10	0.39	0.39	0.35	0.18	0.12	−0.05	−0.05	−0.06	−0.09	−0.18	0.18	0.19	0.19	0.17	0.14	0.01	0.01	−0.11	1.00

Table 3. Poisson regression of the impact of technical capital, commercial capital, social capital, and important inventions on linkage formation

Variable	Technical Links Formed$_{it}$ (Total)								Technical Links Formed$_{it}$ (Joint Ventures)	Technical Links Formed$_{it}$ (Research Agrs)
	1	2	3	4	5	6	7	8	9	10
Intercept	−1.201***	−1.144***	−1.137***	−1.503***	−1.362***	−1.132**	−1.167***	−1.166***	−1.722***	−1.982***
	[0.308]	[0.304]	[0.309]	[0.320]	[0.322]	[0.347]	[0.349]	[0.348]	[0.466]	[0.533]
Technical Capital (Patents, ’00’s)$_{it-1}$		0.126***	0.035^{+}	0.131***	0.123***	0.104***	0.100***	0.100***	0.081*	0.131**
		[0.014]	[0.024]	[0.028]	[0.028]	[0.029]	[0.030]	[0.029]	[0.039]	[0.045]
Commercial Capital (Assets, $bn)$_{it-1}$			0.080***	0.217***	0.161***	0.150***	0.148***	0.148***	0.110**	0.204***
			[0.015]	[0.026]	[0.030]	[0.031]	[0.031]	[0.030]	[0.040]	[0.048]
Technical *Commercial$_{it-1}$				−0.015***	−0.012***	−0.010***	−0.010***	−0.010***	−0.006*	−0.014***
				[0.002]	[0.002]	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]
Social Capital (Prior Degree Centrality)$_{it-1}$					0.051**	0.024	0.023	0.023**	0.042***	0.002
					[0.021]	[0.024]	[0.024]	[0.009]	[0.012]	[0.013]
Social Capital (Prior Degree Centrality) Sqr$_{it-1}$					−0.0008	−0.0001	−0.00001			
					[0.0006]	[0.0007]	[0.0007]			
Capital-Poor Firm *Important Inventions$_{it-1}$							−0.133	−0.133	0.424	−28.049
							[0.802]	[0.802]	[0.784]	[2.38e6]
Capital-Poor Firm *Important Inventions$_{it-2}$							0.412	0.412	0.900*	−0.214
							[0.419]	[0.419]	[0.504]	[0.822]
Capital-Poor Firm *Important Inventions$_{it-3}$							0.644^{+}	0.644	0.328	0.768*
							[0.401]	[0.401]	[0.822]	[0.462]
Capital-Poor Firm *Important Inventions$_{it-4}$							0.849	0.850	1.354*	−28.760
							[0.734]	[0.734]	[0.755]	[2.91e6]

Table 3. Continued

Variable	Technical Links Formed$_{it}$ (Total) 1	2	3	4	5	6	7	8	Technical Links Formed$_{it}$ (Joint Ventures) 9	Technical Links Formed$_{it}$ (Research Agrs) 10
Capital-Poor Firm						–0.418** [0.165]	–0.485** [0.171]	–0.486** [0.160]	–0.495* [0.226]	–0.475* [0.227]
Important Inventions$_{it-1}$						–0.083^{+} [0.059]	–0.079^{+} [0.060]	–0.079^{+} [0.059]	–0.130^{+} [0.084]	–0.033 [0.085]
Important Inventions$_{it-2}$						0.094* [0.054]	0.090* [0.054]	0.090* [0.054]	0.108^{+} [0.072]	0.071 [0.081]
Important Inventions$_{it-3}$						–0.058 [0.062]	–0.068 [0.063]	–0.068 [0.063]	–0.032 [0.086]	–0.106 [0.093]
Important Inventions$_{it-4}$						–0.030 [0.059]	–0.032 [0.059]	–0.032 [0.059]	–0.050 [0.082]	–0.024 [0.086]
Marketing Linkages$_{it-1}$	0.181*** [0.026]	0.130*** [0.027]	0.129*** [0.027]	0.082** [0.028]	0.053^{+} [0.029]	0.059* [0.029]	0.060* [0.029]	0.060* [0.028]	0.107** [0.039]	0.015 [0.042]
Debt/Equity$_{it-1}$	–0.0004 [0.013]	0.005 [0.013]	0.007 [0.013]	0.019 [0.014]	0.017 [0.014]	0.016 [0.014]	0.016 [0.014]	0.016 [0.014]	0.019 [0.017]	0.006 [0.024]
Current Ratio$_{it-1}$	–0.095 [0.092]	–0.111 [0.089]	–0.019 [0.091]	0.019 [0.094]	–0.032 [0.096]	–0.016 [0.103]	–0.012 [0.103]	–0.012 [0.103]	0.101 [0.136]	–0.162 [0.161]
Return on Assets$_{it-1}$	0.838 [1.734]	0.519 [1.782]	0.374 [1.836]	2.289 [1.878]	1.845 [1.865]	1.311 [1.871]	1.281 [1.874]	1.282 [1.872]	1.825 [2.463]	0.715 [2.900]
Diversification (Entropy)$_{it-1}$	0.633*** [0.134]	0.184 [0.147]	0.085 [0.148]	–0.028 [0.148]	–0.006 [0.151]	–0.018 [0.151]	0.016 [0.152]	0.016 [0.152]	–0.038 [0.217]	0.051 [0.214]
Summed Coefficients										
Capital-Poor Firm *Important Inventions							1.773^{+}	1.773^{+}	3.006*	–56.254
4-period							[1.283]	[1.283]	[1.543]	[3.78e6]
Important Inventions						–0.077	–0.089	–0.089	–0.105	–0.092
4-period						[0.097]	[0.105]	[0.097]	[0.129]	[0.151]
N	840	840	840	840	840	840	840	840	840	840
Chi-sq./d.f.	178.6/25	252.0/26	279.5/27	323.1/28	334.9/30	347.4/35	351.0/39	351.0/38	215.6/38	200.7/38
2 log likelihood *vis-à-vis* preceding models	73.43***	27.48***	43.56***	11.85**	12.51*	3.62	–0.0004			

$^{+}p < 0.1$; $*p < 0.05$; $**p < 0.01$; $***p < 0.001$. One-tailed tests for hypothesized variables, two-tailed tests for controls. The table gives parameter estimates; standard errors are in brackets. All models include 9 Year and 12 Nation dummies that are not presented in the table owing to space constraints.

Model 6 includes the four lagged versions of the Important Inventions variable, and the Capital-Poor variable. Model 7 adds the four interaction terms between the Important Inventions and Capital-Poor variables and completes the specification. The chi-square statistics of the likelihood ratio tests indicate that every additional variable improved model fit with one exception: the inclusion of the square term of the Social Capital variable did not significantly improve model fit. Therefore, I ran a final model, Model 8, after omitting the squared term on Social Capital. Table 3 also includes two additional models (Models 9 and 10, respectively) using **Technical Links Formed (Joint Ventures)** and **Technical Links Formed (Technology Agreements**) as the dependent variables, respectively.

Examining the results of the final specification (Model 8) in Table 3 I note that they provide complete support for Hypotheses 1, 2, 3, and 5, and partial support for Hypothesis 4. Specifically, in Hypothesis 1 I predicted a positive relationship between the level of technical capital owned by a firm and the number of linkages formed by it. This hypothesis was supported as the coefficient on Technical Capital was positive and significant. In Hypothesis 2 I predicted a positive relationship between the level of commercial capital owned by a firm and the number of linkages formed by it. This hypothesis was also supported as the coefficient on Commercial Capital was positive and significant. In Hypothesis 3 I predicted a negative relationship between the interaction of technical and commercial capital and the number of linkages formed by a firm. This hypothesis was also supported as the coefficient on the interaction term was negative and significant.

Using a simple illustration to compare the effects of a change in technical capital on the linkage-formation behavior of firms at different levels of commercial capital may provide one way of interpreting the above results. Consider two firms with different levels of commercial capital within the observed range of values on this variable at 2.00, and 12.00, respectively. In quantitative terms, the coefficients in Model 8 suggest that increasing technical capital by one standard deviation *increases* the linkage formation rate by 24 percent for the firm with commercial capital of 2.00 $[0.1-(0.01*2.00)]3$. Thus, increasing a firm's technical capital leads to a higher linkage formation rate, indicating the firm's increasing attractiveness as a partner. However, for the firm with commercial capital at 12.00, increasing technical capital by one standard deviation *decreases* the rate of linkage formation by 6 percent $[0.1-(0.01*12.00)]3$, suggesting that for firms possessing high levels of commercial capital, higher levels of technical capital lead to a reduction in the firm's linkage formation rate.

In Hypothesis 4 I predicted a curvilinear relationship between a firm's level of prior social capital and the number of linkages formed by it. This hypothesis was only partly supported as the squared term on the Social Capital variable was rejected by the model but the coefficient of the Social Capital variable by itself was positive and significant. Thus, linkage formation increases with social capital, but a curvilinear effect cannot be identified. One possible explanation for failing to observe the downward-sloping part of the social capital prediction is that the saturation point beyond which further linkage formation activity is undesirable was possibly not reached, at least not by a sufficient number of firms so as to indicate a statistically significant impact.

An issue of some intrinsic interest would be to compare the relative strengths of the three forms of capital as influences on linkage formation. Since the Poisson regression is nonlinear the effect of individual regressors is conditional on the values of the regressors. For the purposes of a simple comparison I estimated the effect of a one standard deviation increase in each of the three forms of capital on a firm that possesses the mean level of each of the three forms of capital. At the mean of the three forms of capital a one standard deviation increase in technical capital increased linkage formation by 22.47 percent, a one standard deviation increase in commercial capital increased linkage formation by 47.36 percent, and a one standard deviation increase in social capital increased linkage formation by 12.28 percent. Thus it appears that for the 'average' firm an increase in commercial capital increases technical linkage formation by almost four times as much as an increase in social capital and twice as much as an increase in technical capital. This result suggests that, at least in the chemicals industry, commercial capital might represent the most important influence on linkage formation for the 'average' firm—even more important than technical capital. Or stated another way, to the extent that one can view the linkage formation arena as a market for obtaining collaborations, it appears that commercial capital is a more highly valued currency for the average firm than is technical capital. Firms lacking complementary assets and commercial capital may be at a greater disadvantage than firms lacking technical capital in trying to compete in the linkage formation arena in the chemicals industry.

To test Hypothesis 5 I summed up the individual coefficients of the four lagged Important Inventions*Capital-Poor Firm variables and tested this summed coefficient against the null hypothesis that its value was zero. The summed coefficient and its standard error are reported in the relevant columns at the bottom of Table 3. The null hypothesis of no impact was rejected in favor of the alternate hypothesis that for capital-poor firms Important Inventions have a positive impact on Links Formed at the 10 percent level of significance. The two component terms of the interaction also provided interesting insights. The coefficient on the Capital-Poor Firms was negative and significant, indicating that such firms were relatively less likely to form linkages in general. Interestingly, the summed coefficient on the Important Inventions variable was not statistically significant. Thus, it appears that Important Inventions translate into linkage formation benefits only for capital-poor firms. This is consistent with the prediction in Hypothesis 5 that the effect of Important Inventions would be greatest for Capital-Poor Firms.

Social Capital was a good predictor of Joint Venture formation but not of Technology Agreement formation. One possible explanation for this finding is that when firms set up Technology Agreements they have sharply focused needs and look for partners with very specific technical capabilities. Hence, social capital may not come into play very significantly in the search process for partners, which may be guided more by technical needs. In the case of Joint Ventures the arrangement may entail a larger scope, necessitate higher levels of operating flexibility and generally require greater interdependence. In such circumstances the value of social capital may be significant. Firms with higher social capital would be more comfortable, making such commitments and would probably do so in a better-informed fashion as their network connections may provide them with some insights into the potential behavior of partners (Gulati, 1999).

The Capital-Poor Firms*Important Inventions variable was also a good predictor of joint venture formation but not of technology agreement formation. One possibility that would be consistent with these results would be that joint ventures are used more often to further develop and commercialize inventions while technology agreements are more commonly used at an earlier stage of the research process, for instance to create new inventions. In such circumstances after creating a breakthrough invention capital-poor firms may be more likely to form a joint venture, rather than a research agreement, to further develop the technology and bring it to market. Such an interpretation would also be consistent with the above finding that commercial capital is significantly more important than technical capital for the 'average' firm in this industry. For instance, one dynamic that would explain both sets of results would be that once a capital-poor firm comes up with an important invention, it needs to obtain access to commercial capital. Firms that are well endowed with commercial capital are more attractive partners and a joint venture is the mechanism by which the inventions are brought to market.

Consistent with prior research (Gulati, 1999) the results in Table 3 provide only weak support for the financial determinants of alliance formation. The coefficients for the three financial control variables, Debt–Equity, Current Ratio and Return on Assets, and for the Diversification variable (Entropy) were insignificant. There was no consistent pattern for the dummy variables for the different Years. This result is broadly consistent with prior research by Gulati (1999), who found no meaningful temporal pattern in alliance formation in his data set, which spans the years 1980–89.

Prior research has found no significant differences in the linkage formation behavior of firms on the basis of nationality (Gulati, 1999). In this study, while the nationality dummies for most countries were insignificant relative to the omitted category of American firms, the nation dummy for Japan was positive and significant while that of the United Kingdom was negative and significant. For Japanese firms one possible explanation is that the study period represents a phase of 'catching up' with the European and American firms (Hikino *et al.*, 1998). During the 1980s Japanese chemical firms followed expansionary strategies based on improving their presence in international markets and building new product development skills to complement their historical emphasis on process improvement (Hikino *et al.*, 1998). These imperatives have been reflected in increased R&D relative to European and American firms (Hikino *et al.*, 1998), and would also be consistent with the increased linkage formation activity that is observed in this study. However, detailed analysis of the national chemical industries would be required to confirm these explanations. Analyzing the role of national industrial circumstances in these trends goes beyond the scope of the current research and is left to future research.

One possibility raised by a reviewer was that since each linkage formed affects two observations in the data set this might lead to under-representation of the true standard errors. One approach to correcting such a double-counting problem is to treat it as an issue of oversampling (Barnett and Carroll, 1993; Baum and Korn, 1996).[6] Oversampling can be corrected by discounting oversampled cases in proportion to the extent of oversampling. For instance, if a firm–year observation in the data set reflects the formation of three linkages by that particular firm in that particular year, the observation would have to be given a weight of 0.25 in the actual maximum likelihood computations. The 0.25 weight for this observation is appropriate because the three linkages reflected in this observation would also be reflected in three other observations: those involving the three partners of this firm. Attaching a weight of 0.25 to each of these four observations (for the focal firm and its three partners) ensures that in the final computation the sum of weights across all four observations equals 1. Thus, this procedure ensures that no linkage is given a weight of more than one in the data. Table 4 presents the results of this analysis, with all models estimated in Table 3 being reestimated using the above weighting scheme. Extensive additional analyses indicated that the results were robust to many specifications.

DISCUSSION AND CONCLUSION

In summary, the results of the empirical analysis provide support for several aspects of the theoretical arguments. First, they provide some evidence that linkage formation behavior is systematically related to both inducements and opportunities. Second, the results indicate that possession of technical, commercial, and social capital—three tenure-related advantages—significantly influence both the linkage formation inducements and opportunities facing firms. Third, the results also support the notion that a firm's creation of an important invention provides an additional path to linkage formation for firms that lack the three tenure-based advantages. These results have implications for resource-based and network theories of organizations as well as for practice and public policy. I discuss some of these implications below.

Implications for theory and research

Research on the resource-based view of the firm has often focused on the make-or-buy alternatives for obtaining resources (Barney, 1986, 1989; Dierickx and Cool, 1989). Barney's original argument was that in any reasonably efficient strategic factor market a rent-generating factor or resource should command a price that reflects its potential for supernormal profits in downstream markets. Hence, once this cost has been factored into the revenues obtained from such an asset the only way a firm can still make supernormal profits is if the firm gets lucky or has unique knowledge of the future value of the asset at the time that it buys the asset. Dierickx and Cool (1989) argued subsequently that the above view assumes that markets exist for all factors, and that all factors can be bought and sold on such markets. Their contention was that the only factors that could be the basis of supernormal profits were those that could not be traded on markets. Such factors could only be accumulated internally, i.e., 'a firm which does not own a non-tradable asset which it requires for the implementation of its product market strategy is constrained to *building* this asset' (Dierickx and Cool, 1989: 1506; italics in original).

This study is part of a nascent stream of research that draws attention to another path that is available to firms for obtaining resources that they need but do not own: sharing the resources with their current owner through an interfirm arrangement (Dyer and Singh, 1998; Eisenhardt and Schoonhoven, 1996). Thus, a firm need not be constrained to 'build'

[6] I thank an anonymous reviewer for drawing my attention to this solution.

Table 4. Weighted Poisson regression of the impact of technical capital, commercial capital, social capital, and important inventions on linkage formation

Variable	Technical Links Formed$_{it}$ (Total)								Technical Links Formed$_{it}$ (Joint Ventures)	Technical Links Formed$_{it}$ (Research Agrs)
	1	2	3	4	5	6	7	8	9	10
Intercept	−1.710*** [0.434]	−1.722*** [0.425]	−1.761*** [0.430]	−2.110*** [0.443]	−1.993*** [0.445]	−1.750*** [0.480]	−1.807*** [0.483]	−1.800*** [0.482]	−2.329*** [0.653]	−2.875*** [0.749]
Technical Capital (Patent, '00's)$_{it-1}$		0.143*** [0.021]	0.048^{+} [0.037]	0.146*** [0.041]	0.137*** [0.041]	0.109** [0.043]	0.104** [0.043]	0.104** [0.043]	0.066 [0.059]	0.139* [0.064]
Commercial Capital (Assets, $bn)$_{it-1}$			0.086*** [0.025]	0.233*** [0.038]	0.177*** [0.043]	0.158*** [0.044]	0.155*** [0.044]	0.156*** [0.044]	0.131* [0.057]	0.215*** [0.069]
Technical *Commercial$_{it-1}$				−0.016*** [0.003]	−0.013*** [0.003]	−0.010** [0.004]	−0.009** [0.004]	−0.009** [0.004]	−0.007^{+} [0.005]	−0.015** [0.006]
Social Capital (Prior Degree Centrality)$_{it-1}$					0.065* [0.031]	0.032 [0.034]	0.031 [0.034]	0.026* [0.013]	0.054** [0.018]	−0.002 [0.019]
Social Capital (Prior Degree Centrality) Sqr$_{it-1}$					−0.001 [0.001]	−0.0002 [0.001]	−0.0002 [0.001]			
Capital-Poor Firm *Important Inventions$_{it-1}$							−0.028 [0.931]	−0.028 [0.931]	0.529 [0.990]	−28.359 [3.63e6]
Capital-Poor Firm *Important Inventions$_{it-2}$							0.622 [0.510]	0.623 [0.510]	1.141* [0.676]	−0.158 [1.050]
Capital-Poor Firm *Important Inventions$_{it-3}$							0.927* [0.484]	0.929* [0.484]	0.364 [1.052]	1.069* [0.603]
Capital-Poor Firm *Important Inventions$_{it-4}$							1.279+ [0.894]	1.283^{+} [0.894]	1.748* [0.992]	−28.896 [4.46e6]
Capital-Poor Firm						−0.486** [0.214]	−0.584** [0.224]	−0.597** [0.210]	−0.599* [0.311]	−0.523* [0.315]
Important Inventions$_{it-1}$						−0.132^{+} [0.091]	−0.125^{+} [0.091]	−0.126^{+} [0.091]	−0.171^{+} [0.129]	−0.051 [0.121]

Table 4. Continued

Variable	Technical Links Formed$_{it}$ (Total)								Technical Links Formed$_{it}$ (Joint Ventures)	Technical Links Formed$_{it}$ (Research Agrs)
	1	2	3	4	5	6	7	8	9	10
Important Inventions$_{it-2}$						0.165* [0.085]	0.158* [0.086]	0.158* [0.086]	0.154^{+} [0.113]	0.065 [0.123]
Important Inventions$_{it-3}$						−0.021 [0.093]	−0.039 [0.094]	−0.040 [0.094]	−0.023 [0.128]	−0.067 [0.131]
Important Inventions$_{it-4}$						−0.035 [0.088]	−0.036 [0.089]	−0.036 [0.089]	−0.059 [0.125]	−0.001 [0.121]
Marketing Linkages$_{it-1}$	0.194*** [0.041]	0.134*** [0.043]	0.120** [0.044]	0.065 [0.045]	0.030 [0.046]	0.033 [0.047]	0.037 [0.047]	0.038 [0.046]	0.088 [0.061]	0.030 [0.064]
Debt/Equity$_{it-1}$	0.006 [0.017]	0.013 [0.017]	0.014 [0.017]	0.028 [0.018]	0.026 [0.018]	0.025 [0.018]	0.025 [0.018]	0.025 [0.018]	0.030 [0.023]	0.005 [0.034]
Current Ratio$_{it-1}$	−0.143 [0.134]	−0.120 [0.129]	−0.035 [0.131]	0.010 [0.136]	−0.029 [0.137]	0.005 [0.146]	0.011 [0.147]	0.012 [0.147]	0.0155 [0.197]	−0.182 [0.227]
Return on Assets$_{it-1}$	0.224 [2.373]	−0.160 [2.442]	−0.215 [2.474]	1.630 [2.546]	1.052 [2.532]	0.584 [2.527]	0.478 [2.532]	0.500 [2.528]	0.672 [3.471]	−0.152 [3.893]
Diversification (Entropy)$_{it-1}$	0.512** [0.195]	0.072 [0.207]	0.024 [0.207]	−0.110 [0.206]	−0.099 [0.211]	−0.122 [0.211]	−0.063 [0.213]	−0.062 [0.213]	−0.156 [0.305]	0.150 [0.306]
Summed coefficients										
Capital-Poor Firm *Important Inventions 4-period							2.800* [1.537]	2.807* [1.537]	3.782* [2.003]	−56.344 [57479]
Important Inventions 4-period						−0.023 [0.138]	−0.043 [0.156]	−0.043 [0.140]	−0.100 [0.193]	−0.055 [0.209]
N	840	840	840	840	840	840	840	840	840	840
Chi-sq./d.f.	769.1/25	810.1/26	821.6/27	846.4/28	854.2/30	864.8/35	869.6/39	869.6/38	632.8/38	607.3/38
−2 log likelihood *vis-à-vis* preceding models		41.03***	11.46**	24.83***	7.73**	10.65^{+}	9.58*	−0.058		

$^{+}$L$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. One-tailed tests for hypothesized variables, two-tailed tests for controls. The table gives parameter estimates; standard errors are in brackets. All models include 9 Year and 12 Nation dummies that are not presented in the table owing to space constraints.

resources provided it can obtain the right to share them. However, as the results of this research indicate, the 'resource-sharing' option is available only to those firms that can pay for this right with an appropriate 'coin of the realm.' As I argue below, usually the appropriate coin of the realm is not just any other factor but a factor with *resource* characteristics.

Note that the attractiveness of a firm on the interfirm linkage market depends on what the firm can provide to its partners. If a firm can only provide tradable factors in exchange for access to *resources* it is unlikely to attract partners for two reasons. First, firms that share resources are in essence sharing the basis of their competitive advantage. They may be willing to do so if in return they obtain access to another resource that they cannot obtain from the market; they will be less willing to trade their competitive advantage for an asset that is available on the market and does not improve their competitive position. Second, from the perspective of bargaining and sharing the gains from an exchange, this exchange is unattractive to the firm sharing a resource. A firm that gives access to one of its resources while receiving a tradable factor in return is sharing its supernormal profit-generating assets in turn for one whose current market value captures its entire future return. The only circumstance under which such trades will occur is if the party providing a tradable resource accepts terms of trade that significantly undervalue its own contribution to the alliance. Thus, the firm can compensate for its lack of resources by paying additional in terms of tradable factors.

The above argument is also consistent with a finding of this paper that has also been observed in other research on linkage formation. Both in this research and in other studies of interfirm linkage formation (Gulati, 1999) the relationship between linkage formation and firm financial factors has generally been found to be weak. In the context of the above discussion of the importance of *resources* in the linkage formation process these results are understandable. In an efficiently functioning capital market financial assets are generally tradable at close to their true market values. Firms willing to share their resources are likely to demand assets from their partners that go beyond the financial assets they can obtain at the going rates from the capital market. Only in the context of capital market imperfections would financial assets become resources that are valued by partners. A testable implication of these arguments that can be examined in future research is that firms possessing only financial assets but lacking resources will be able to obtain partners only after discounting their financial contributions significantly, relative to the going rates for the relevant financial assets.

This research also highlights an important insight into the relationship between firm resources and firm performance. The findings of this paper demonstrate that firms' prior accumulation of capital influences their current opportunities significantly. Thus, it draws attention to the fact that not only do prior stocks of capital and resources influence performance outcomes, but they also constrain or limit the strategic choices available to firms. The resource-based view of the firm suggests that rare and inimitable capabilities and commitments are sources of supernormal firm performance. Research in this stream suggests that causal ambiguity in the relationship between resources and supernormal performance is one mechanism through which inimitability operates (Lippman and Rumelt, 1982). These results highlight another mechanism through which the link between firm-specific resources and supernormal performance may operate—differences in the set of opportunities available. Knowing that collaboration with an appropriate partner can be a mechanism for improved innovative capabilities is not the same as being able to establish a collaborative relationship. To accomplish the latter a firm has to compete with other firms in the linkage-formation arena. In such a competition firms with higher levels of capital are likely to be attractive to many more partners and have a greater likelihood of realizing the portfolio of collaborations they seek than less-endowed firms. Well-executed collaborations can improve performance but these improvements can occur only for those firms that obtain partners in the first place.

The theory and findings of this paper also have implications for network research. Several authors have noted that network research suffers from the conspicuous deficiency that the process of network formation and transformation is underspecified (Emirbayer and Goodwin, 1994; Gulati and Gargiulo, 1999; Madhavan *et al.*, 1998). Recent studies have moved to correct this deficiency but have used predominantly sociological arguments to explain the emergence of network structure (Gulati, 1998; Gulati and Gargiulo, 1999; Walker *et al.*, 1997). Further, these studies have emphasized the dynamics generated by the developing network as the causal factor for network transformation rather than the behavior of individual actors. In essence, these studies have applied network theoretic arguments at the level of the network to explain the generation of future network structure. Although these explanations have been insightful, a logical next step is to expand these arguments to include the broader set of factors that are likely to influence network formation and to explicitly recognize the motivations and ability of the individual actors in the network (Eisenhardt and Schoonhoven, 1996; Madhavan *et al.*, 1998). This study has sought to advance research along these dimensions.

To move beyond the sociological dynamics underlying network formation, and identify the broader set of factors driving interfirm collaboration, this study used the resource-based perspective. Utilizing this perspective to inform the issue of network formation was both advantageous and limiting. On the positive side this perspective enabled a systematic identification of the kinds of resources that may be relevant to a general theory of network formation for business firms. Further, it also facilitated the inclusion of individual actors' inducements and opportunities as determinants of the process of network formation.

However, the instrumental view of actor behavior that is adopted by the resource-based perspective also serves to limit the generalizability of this research. The presumption that actors are driven by a search for competitive advantage, which is central to the resource-based view and to the framework used in this paper, may not be valid in other network contexts. Consequently, the applicability of the theory and findings of this study must be limited to networks of for-profit organizations. The general approach of using one theoretical perspective to inform another may, however, be useful in further network research.

A final contribution of this research to the network literature concerns its direct inclusion of the impact of technology on the structuring of interorganizational networks. The impact of technology on organizational structure has been extensively studied. Far less research has examined the impact of technology on network structure. Prior research of the impact of technology on network structure has examined either a single organization (Burkhardt and Brass, 1990) or a single technology shock (Madhavan *et al.*, 1998). This study presents a more general test of the role of technology in network structuring by studying multiple firms over multiple time periods and including both discrete and continuous components of technical change.

Implications for public policy

Prior research has argued for a more permissive antitrust treatment of collaborative activity and a liberalization of antitrust law (Jorde and Teece, 1990). However, the results of this study do not support such a move. The results of this study indicate that the ability to collaborate is not evenly distributed in the population of firms. Specifically, firms with a history of collaboration, high technological strength, and commercial assets enjoy greater facility in obtaining partners. The finding that commercial capital is relatively more important in influencing linkage-formation behavior further reinforces the nature of the incumbency advantage in this arena. Under such circumstances a relatively restrictive antitrust policy *vis-à-vis* collaboration may actually benefit the firms which lack these advantages by leveling the playing field for them. This inference is made on the assumption that a more restrictive antitrust policy will *de facto* affect market leaders more than it will affect small firms which lack market power. By the same token a more liberal antitrust policy would probably benefit the established firms more. In the longer run such a policy, in conjunction with the advantages in linkage formation already possessed by this group of firms, may allow them to collaborate at increasingly higher levels and eventually dominate the industry. In technologies marked by network externality characteristics, such as software, such an outcome could be both highly possible and extremely anticompetitive. In the light of this danger it is suggested that any measures intended to liberalize antitrust policy be analyzed with caution in this regard.

Implications for managers

These arguments and findings draw managers' attention to the notion of *resources* as the fundamental basis for both inducements and opportunities in the context of linkage formation. Recognizing that the assets shared through collaboration are usually difficult to obtain through markets should inform the terms of trade that managers use to negotiate such linkages. Clearly, one possible precept is to suggest that when managers provide access to one of the focal firm's *resources*, they should ensure that they obtain access to a partner's *resources* in return. Alternately, if a partner is only providing a tradable asset, managers of the focal firm need to ensure that the asset is reflected in the partnership at a discount to its market value to compensate the focal firm for its relatively greater sacrifice.

Limitations and future research

Future research could improve and build on this paper in several directions. First, the measurement of technical capital that was used in this research relies on patent data. Clearly, many forms of technical capital are not patentable and hence are ignored in this research. Learning by doing, nonpatentable technical knowledge and processes, and human skills are likely to be important components of the technical capital of firms. Future research could investigate the role such forms of capital play in the context of linkage formation. The measure of commercial capital could also be improved with the availability of finer data.

Another direction of future research would be to develop further the basic model of exchange presented in this paper. One specific direction of such development would be to explore at greater depth the relationship between social capital and technical and commercial capital. In this paper greater attention was attached to the roles of technical and commercial capital, and social capital was treated as facilitative. However, it could be argued that in certain industrial contexts social capital could well have an equivalent, or indeed greater, role. Developing a general model of exchange that incorporates all three forms of capital and examines in some depth the interactions between social capital and the other two forms of capital would be a natural next step from this research.

Finally, the firm-level analysis of collaboration done in this research could be supplemented with dyadic level analysis. This paper addressed only the issue of how many linkages a firm would form. An equally interesting question would be to ask, who links with whom? Geographic proximity (Zaheer and Zaheer, 1999), complementarity considerations (Kale et al., 2000), and competitive provocations (Garcia-Pont and Nohria, 1999) are all likely to be influential in determining the dyadic patterns of collaboration that finally come to fruition. Understanding the 'structure of cooperation' in this fashion would be a useful counterpoint to the work examining the 'structure of competition' (Zaheer and Zaheer, 1999).

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