CHOOSING A PARTNER

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Abstract: This paper investigates the effect of network embeddedness on the firm's cost-benefit calculus for selecting R&D partners. Both knowledge and market networks are considered. We find strong evidence that firms prefer 'localized' R&D collaboration in order to lower transaction costs and increase the opportunities for learning. Firms also tend to pick central network players with whom they have collaborated before. Prior networking experience, product complexity, and involvement in general purpose technologies further raise R&D partner attraction. Formal intellectual property protection mechanisms such as patents loose some of their appeal in networked environments.

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1. Introduction

One of the most striking features of industrial innovation today is that only a small minority of firms innovate alone. Innovations typically involve constellations of organizations (Gomes-Casseres, 1996). This is especially the case for the most valuable, most knowledge-intensive, and most complex technologies. The past couple of decades have witnessed the explosion of cooperative agreements involving firms, universities, other research institutes, and "intermediate organizations" (e.g., professional and trade associations, think tanks) in various combinations (Hagedoorn, Link and Vonortas, 2000; Jankowski, Link and Vonortas, 2001).

Adapting to an environment of high risks, global competition, increasing cost and complexity of different technological advances, and rapid generation and diffusion of technical knowledge and know-how, a large number of firms have opted for cooperative relationships. These linkages are complex, involving not only diverse kinds of formal contracts, but also informal exchanges of knowledge. In the presence of technological development that involves a greater array of product and process systems, subsystems, and components, no single firm can deploy all of the required core capabilities and complementary assets at a reasonable cost. In this context, a network serves as a locus for innovation because, for any network member, it provides timely access to external knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning abilities (Gulati, 1998, 1999).

Innovation networks is our term to describe the complex webs of relationships among firms, universities, and other organizations for generating and sharing knowledge relevant to innovation. Innovation networks involve a wide range of collaborative activities, including joint ventures, research corporations, joint research and development (R&D), technology exchange agreements (e.g., technology sharing, cross-licensing, mutual second-sourcing), direct investment, customer-supplier relations, R&D contracts, one-directional technology flow agreements (e.g., licensing, second-sourcing), manufacturing agreements, and so forth. Innovation networks also often involve informal collaboration and knowledge exchanges across individuals in different organizations and systemic learning through patents, blueprints, etc.

This paper deals with one kind of innovation networks, those formed around research partnerships. Following Hagedoorn et al. (2000), a research partnership is broadly defined as an innovation-based relationship that involves, at least partly, a significant effort in research and development (R&D). The specific research partnerships that provide the analytical basis for the paper are officially called research joint ventures (RJVs) by the US Department of Justice.

The paper draws on various strands of literature on strategic partnering ranging from mainstream microeconomic analysis to strategic management and network theory in order to formulate a set of analytical hypotheses regarding the choice of specific partners to collaborate with. These hypotheses are then tested with the help of an extensive panel dataset that provides longitudinal information on a large set of R&D-based collaborative ventures and on their participants, including the inter-temporal technological and market performance of participating firms and the characteristics of their industries.

More specifically, the paper investigates the effects of the knowledge and market networks in which firms are embedded on their cost-benefit calculus regarding partner choice for R&D cooperation. We find strong evidence that firms prefer to venture close to home in terms of technological capabilities and market specialization when choosing partners. Collaborating with organizations with similar characteristics lowers transaction costs and increases the chances for learning. Partnering with central network players with whom the firm has collaborated before keeps costs low while reinforcing learning possibilities. Prior networking experience, product complexity, and involvement in general purpose technologies further raise R&D partner attraction. Formal intellectual property protection mechanisms such as patents lose some of their appeal in networked environments.

The rest of the paper is structured as follows. Section two summarizes the prevalent analytical approaches to inter-firm collaboration. Section three lays out the research hypotheses. Section four describes the data, variables, and the analytical methodology. Section five discusses the empirical results. Finally, Section six concludes.

2. Perspectives on Technology Collaboration[1]

The theoretical perspectives on R&D collaboration can be divided into two broad strands. The first strand approaches the topic under the rubric of cost-benefit analysis of standard microeconomics and includes the mainstream industrial organization perspective and the transaction costs and incomplete contracts perspective. The second strand relates to the strategic management literature and stems from the theories of the firm that view partnering as a mechanism to bundle resources, build capabilities, and create future technological and market opportunities.

2.1. Microeconomic perspectives

Mainstream industrial organization literature

The industrial organization literature on R&D collaboration basically reflects two major methodological streams. One stream emphasizes the "timing of innovation" where the winner of a "technology race" earns the right to some exogenously or endogenously determined monopolistic return (tournament models). The analytical focus has been on determining the number of firms that enter the race, the aggregate R&D investment and its distribution across firms and time, as well as the effects of market power, technological advantage and technological uncertainty (Beath et al., 1995; Martin, 1994, 1999). The strengths of tournament models are the explicit role of time and uncertainty and their ability to handle both product and process innovations. A weakness is that these models relate more to discrete technical advances and may not be able to accommodate sufficiently well technological competition in cases where technologies are continuously upgraded but are not radically different than their predecessors.

The second stream has concentrated on the "extent of innovation" (non-tournament models), usually approximated by the degree of cost reduction (Dasgupta and Stiglitz, 1980; Brander and Spencer, 1983; Spence, 1984). Firms are assumed to invest in

[1] This Section draws extensively on Caloghirou et al. (2003), Joshi and Vonortas (1997), and Lee and Vonortas (2002).

R&D in order to decrease costs and then compete in terms of prices or outputs in product markets. A large number of static (atemporal) analyses of both cooperative and noncooperative industrial set-ups with imperfectly appropriable, cost-reducing R&D have followed the seminal paper by d'Aspremont and Jacquemin (1988) in this stream of thought.[2] These papers investigate the relative efficiencies of competition and cooperation in R&D in raising final output production and enhancing social welfare. The strengths of the non-tournament models include that they link better to the case of continuously upgraded technologies. A large number of these models incorporate knowledge spillovers. Unfortunately, the bulk of the non-tournament literature has been confined to static (even though multistage) models of strategic interaction and "naive" dynamic games (supergames), with few examples of formal dynamic analysis of cooperative R&D, especially when uncertainty is also considered.[3]

Transaction costs economics and incomplete contracts

The firm can be viewed as a multi-person organization, to be explained on the basis of formal contracts among asset owners. Contracts essentially align the incentives under which the firm's resources operate jointly. Transaction costs economics is the major strand in this "contractarian" perspective on the firm. Following Coase's (1937) seminal contribution, the notion of transaction costs has been greatly refined by Oliver Williamson (1975, 1985) who attempts to operationalise it by specifying the assumptions about human behavior - opportunism and bounded rationality - and the attributes of transactions – mainly asset specificity - that together may give rise to transaction costs. Entrepreneurs will try different ways to organize a transaction, including displacing the market by an administrative hierarchy. The boundary between the market and the firm will be determined by the relative costs of carrying out a transaction under each organizational structure. Where an administrative organization is expected to produce the highest return, arm's-length markets will be displaced, and vice versa.

[2] They include, for example, Spence (1984), Katz (1986), de Bondt and Veugelers (1991), de Bondt, Slaets and Cassiman (1992), Kamien et al. (1992), Suzumura (1992), De Bondt (1997), De Bondt and Wu (1994), Simpson and Vonortas (1994), and Vonortas (1994).
[3] See Joshi and Vonortas (1997) for an exception.

Transaction costs increase steeply when contracts are incomplete, that is, when they do not specify fully the actions of each party in every contingency. A frequent cause of incomplete contracts is small number bargaining usually a result of high asset specificity (Hart and Holmstrom, 1987; Williamson, 1975). A form of assets that has frequently made it very hard, or even impossible, to write complete contracts is the intangible assets belonging to a firm, the most formidable of which may be technological knowledge. Such knowledge can be explicit, in the form of a patent or design, or implicit (tacit) in the form of know-how shared among the firm's employees. Spillovers, un=certainties, and opportunistic behaviour seriously hamper the markets (Arrow, 1962; Jaffe, 1996; Link and Tassey, 1987; Nelson, 1959).

The explanation of research partnerships provided by transaction costs theory is quite straightforward. Partnerships are hybrid forms of economic organization that aim at economizing on transaction costs (Menard, 1996a, 1996b; Williamson, 1996). In the area of R&D these costs may be very high due to spillovers, incomplete contracts and the possibility of opportunistic behaviour that they entail. Therefore, research partnerships become efficient governance structures by limiting partners exposure to research costs, risk, and by allowing better access to resources and markets.

Foss (1998) summarizes the limits of the transaction cost approach: 1) an implicit assumption that alternatives are given, thus depicting agents as having to choose among a clearly defined set of contractual alternatives; 2) a suppression of process, i.e. a view that the optimal solution to the contract design-problem continues to be optimal throughout contract execution; and, 3) a set of strong knowledge assumptions leaving no room to theory to conceptualise the discovery by agents of what was hitherto unimagined. In a nutshell, transaction costs economics treats the contracting agent as a “contract-taker” rather than a learning and creative actor.

2.2. Strategic management perspectives

The formation of technology-based alliances in a modern business environment is considered in this literature as a vehicle of strategic change and of shaping competition. The co-ordination and sharing of the value chain with other partners, the joint creation of value, the accumulation and reconfiguration of resources, the development of new resources, the building of new capabilities and core competencies, and the organisational learning are critical factors in the formation and operation of technical alliances.

Shaping the competitive environment

Research partnerships have been viewed as efforts by firms to shape the competitive framework within which they will operate. The competitive force approach, (Porter 1980, 1985, 1990; Harrigan 1988; Hagedoorn 1993) focuses on the consideration of inter-firm collaboration as a means of shaping competition and improving a firm's comparative competitive position, by sharing value chains with other partners in a way that broadens the effective scope of its chain. The strategic behaviour approach, on the other hand, focuses on the strategic action that a firm takes in order to influence its market environment i.e. to reduce competition by actual or potential rivals. This approach has been used to study strategic decision-making for inter-firm technological cooperation (Porter and Fuller, 1986; Hamel et al., 1989).

Emphasizing resources and capabilities

Edith Penrose's (1959) seminal work founded an analytical approach according to which firm resources are valuable, rare, non-substitutable, and not easily imitable. Thus, firms within an industry or a strategic group may be heterogeneous with respect to the strategic resources they control. In order to fully exploit the existing stock of heterogeneous and immobile resources and to develop sustained competitive advantages, a firm may need access to external complementary resources (Richardson, 1972).

This perspective introduces a dynamic element in the theory of the firm; it views its growth as an incessant process of creating, developing and realigning the capabilities of its resources. Historical time is important in this context, in the sense that as firms interact with their environment, they create conditions that are genuinely irreversible. The irreversibility of time highlights the problem of uncertainty, as the condition in which any strategic decision has to be made. It is not merely the uncertainty of market configuration that is relevant here, for the interaction among the firm's resources tends to produce routines (Nelson and Winter 1982) that are largely tacit, so that management has only a limited capacity to control them (Witt 1998, Ioannides 1999a and 1999b). Therefore, the growth of the firm is a path dependent process, also applying to the direction and the rate at which new knowledge is obtained and becomes effective. Capabilities can be developed within the firm but can also be obtained through the market.

David Teece (1982, 1986, 1992) has developed a very similar framework, usually referred to as the dynamic capabilities approach. This is a further elaboration of the resource-based view of sustained competitive advantage through collaboration. Its novel contribution is that it views capabilities not as static attributes but, rather, as the ability of the firm to adapt to, and gain competitive advantage in a rapidly changing environment. Furthermore, Prahalad and Hamel (1990) have introduced the term "core competencies" to refer to the central strategic capabilities of a firm. These refer to the "collective learning in the organisation especially how to coordinate diverse production skills and to integrate multiple streams of technologies". In particular, Hamel (1991) promotes a skills-based view of the firm by considering it as a portfolio of core competencies and encompassing disciplines. Inter-firm competition is based on knowledge acquisition and skills building. Inter-firm collaboration can be, then, seen as a mode of skill acquisition and capability building/upgrading. In the context of this second group of theories, therefore, the decision to form an alliance represents a strategic decision aiming at developing the resource base of a firm (Glaister, 1996).

Emphasizing knowledge and uncertainty

Another group of analysts emphasizes the role of knowledge and uncertainty on research collaboration. Badaracco (1991) considers strategic technical alliances as a consequence of the globalisation of knowledge. Industry is facing increasing pressures worldwide – such as increasing breadth, tempo and scale of technology, decreasing product life and design time, increasing complexity of product requirements. Going-it-alone becomes an increasingly unfeasible strategy. Firms react to these pressures by pursuing both formal and informal co-operative relationships.

A second approach considers R&D collaboration as a driving force for learning and knowledge creation (Kogut 1988, Ciborra 1991, Pavitt, 1988). Granstrand *et al* (1990) suggest that firms confront some difficulties in integrating competencies and knowledge that come from areas where they are not familiar with. Cooperative agreements can stimulate and facilitate dealing with new technologies and technological change as they can use cooperation for learning that enables them to enter new technological areas (Dodgson, 1991) and deal with technological and market uncertainty (Ciborra, 1991). Cooperative agreements open the range of technological options to firms as they accumulate knowledge that might be converted into new technological and organisational innovations. Two dimensions can thus be assigned to the cooperation: a driving force for learning and creating new knowledge and new competencies and a mechanism for implementation of new knowledge and diffusion in the organisational and inter-organisational level (Llerena, 1997).

A third related approach stems from the importance of uncertainty, and considers R&D collaboration as a tool to create "options" in radically new technologies (Hurry, 1994; Dixit and Pindyck, 1995; Trigeorgis, 1996). The dynamic capabilities perspective mentioned earlier stresses the importance of exploiting existing resources and capabilities as well as developing new ones. However, the theory itself says little about how managers can determine prospectively the set of resources and capabilities that will lead to superior performance in the uncertain environment of dynamic markets (Sanchez, 1993). To obtain superior performance and maintain competitive advantage over its rivals, a firm must constantly choose investment options that correctly match the firm's capabilities with opportunities.

Bowman and Hurry's (1993) strategy-making process model, which integrates resource allocation, sense making, organizational learning, and strategic positioning suggests that options actually form the inimitable resources that give an organization its sustained performance and competitive advantage. Sanchez's model (1993, 1995) also views strategy as a process of continually trying to optimize a firm's strategic options. The model can be applied to evaluating the ways in which different organizational schemes (markets, networks, hierarchy) of the firm's value chain may contribute to or impede the firm's ability to optimize its strategic options. Sanchez suggests that "strategy as strategic options optimization" is consistent with strategy theories based on achieving market power and superior efficiency, and is closely related to the resource-based view of the firm. In a related tone, Kogut (1991) suggests that joint ventures are often set up to establish real options to expand contingent on future technological and market developments. Under certain conditions, a joint venture will essentially allow a firm to buy time before committing to a significant investment.

Overall, option theory suggests that a strategic technology alliance that allows resources to be incrementally committed contingent on positive outcomes will often be more attractive than precommitting the full expected cost for developing a new technology, especially in the presence of high market and technological uncertainty. A project can, then, be considered as a series of options: the firm can choose to stop buying subsequent options contingent on prior outcomes. Through technological collaboration, firms may develop strong working relationships and gain valuable experience and capability, which increase their exposure to related markets and their ability to sense and respond to new opportunities. In other words, the knowledge obtained through the partnership not only increases the number of future options available to the firm but also allows it to evaluate those options better.

The fact that there is a limit to the downside risk to which a technology alliance participant (option holder) is exposed makes the value of the alliance membership increase with uncertainty. This feature is of fundamental importance to understanding the explosion of inter-firm strategic technical alliances around the world since the early 1980s. It also provides a basic justification for RJV formation in the early (fluid) stages of an industry's development. The higher the technological and market uncertainty (volatility) is, the more attractive cooperation becomes for firms that are not willing to "bet the farm".

Networks

Based on early models such as that of Håkansson and Johanson (1984), the strategic network approach is more or less related with all perspectives shown in this Section. Networks allow the exploitation of economies of scale and scope, can lower transaction costs or raise transaction benefits - especially in cases where a high level of trust among partners is being established - and give the opportunity for the joint creation of new value through technological development.

It is more recently though that innovation networks have widely been regarded as the dominant organizational mode in the knowledge-based economy. Economic success in knowledge-intensive industries depends on the commercialization of technologies that require continuous organizational learning. This has created a proliferation of literature, with several special issues and individual papers on alliances and networks appearing in the past few years in journals such as the *Academy of Management Journal* (edited by Osborn and Hagedoorn, 1997), *Organization Science* (edited by Koza and Lewin, 1998), *Organization Studies* (edited by Grandori, 1998), *International Studies of Management and Organizations* (edited by Ebers and Jarillo, 1998), *Strategic Management Journal* (edited by Gulati et al., 2000), and *Journal of Technology Transfer* (edited by Arvanitis and Vonortas, 2000). Several research projects in Europe have also dealt with aspects of networks formation and knowledge communication, including two we are more familiar with (Caloghirou and Vonortas, 2000; Caloghirou et al., 2001).[4] In addition, several review articles, such as Caloghirou, Ioannides and Vonortas (2003), Gulati (1998, 1999), Oliver and Ebers (1998), Hagedoorn, Link and Vonortas (2000), as well as numerous books such as Nohria and Eccles (1992), Nooteboom (1999) and Vonortas (1997) have tried to map the literature on alliances and networks.

While the field remains complex and ambiguous, a couple of viewpoints have gained wide support:

(a) The theoretical foundation of the studies on strategic alliances has been shifting from a mainstream industrial organization perspective (De Bondt et al., 1992; Suzumura, 1992; Vonortas, 1994) and a transaction cost economics perspective (Williamson, 1985, 1991; Menard, 1996a, 1996b) that viewed each alliance as an island, towards a systems view leaning heavily on the concepts of the resource-based view of the firm (Teece, 1992; Eisenhardt and Schoonhoven, 1996) and of learning networks (Gulati, 1995, 1998; Powell et al, 1996; Walker, 1998; Oliver, 2001).

[4] For particularly relevant examples see the papers by Verspagen (2001) and Breschi and Cusmano (2001).

(b) There is a pressing need to understand the longitudinal aspects of inter-organizational networks, particularly how they evolve through time and co-evolve with the degree of maturity of the industry, the firm, and the technology.

This paper recognizes both these developments in an empirical appraisal of the decision process involved in choosing a specific partner to collaborate.

3. Analytical Hypotheses

We were interested in investigating the effects on partner choice (a) of the knowledge and market networks in which firms are embedded, (b) of the expected benefits from the partnership in terms of R&D spillovers and learning opportunities, and (c) of the relationship between the partners and the anticipated transaction costs of the collaborative activity. Recent work on licensing agreements by one of the authors has shown the likelihood that two firms will engage in a licensing agreement to mainly depend on the relationship between the firms and on their characteristics, including the closeness of their technological and industry profiles, familiarity with each other through prior interaction, previous licensing experience, and the strength of intellectual property protection. All these factors work to decrease licensing transaction costs (Kim and Vonortas, 2003). We set out in this paper to investigate how a similar set of factors are weighed in choosing partners in research partnerships. In particular we hypothesize:

H1. Firms will tend to collaborate in R&D:

(a) the closer their technological profiles;
(b) the closer their industry specialization profiles;
(c) the higher the prospective R&D spillovers they can benefit from.

Hypothesis H1 implies the virtues of ‘localized’ R&D cooperation: birds of a feather stick together. Similarities in technological capabilities and market specialization can be associated with lower costs for cooperation. The attraction is intensified by higher expected rates of learning in the partnership due to higher knowledge spillover rates.

H2. Firms will tend to collaborate in R&D:

(a) the more familiar they are with each other through prior agreements;

(b) the more central positions they occupy in the knowledge network;

(c) the more central positions they occupy in the alliance network.

Hypothesis H2 complements H1 directly by introducing network effects. The hypotheses further addresses the importance of value creation through alliances: it juxtaposes cost considerations, on the one hand, by looking at the issues of trust and control through the alliance network and benefit considerations, on the other, by stressing the importance of learning through the technology network. Familiarity through prior interaction among two firms builds trust and understanding of each other which naturally lowers the transaction costs of the next collaborative activity between them. The more central positions the firms occupy in the alliance network the higher the level of mutual assurance that neither will shirk from the obligations of the agreement. Centrality in the knowledge network would imply higher opportunities for learning from partners, especially if combined with higher knowledge spillovers.

H3. Firms will tend to collaborate in R&D:

(a) the higher their prior independent experience with research partnering;

(b) the more complex their main technological fields are; and,

(c) the stronger the intellectual property protection in their business.

Finally, hypothesis H3 seals the case for transaction costs as important factors in R&D collaboration by introducing the more general context in which such agreements are initiated and operate. On the one side is the general strategy of the firm. More experienced firms with alliances will have already developed capabilities with handling the more typical complications one expects in alliances such as negotiating a well structured and yet flexible agreement with appropriate mechanisms of adaptation to changing external conditions, dispute resolution among partners, and eventual dissolution of the partnership. Experience is used here as a surrogate of firm strategy which, for some firms, is much more inclined toward engaging in alliances than in others. On the other side are the overall characteristics of the industry. More complex products can be argued to induce networking as fewer firms are capable to deal in-house with all different technologies involved. Complex product industries, however, may be characterized by lower overall levels of intellectual property protection that, while increasing the level of knowledge spillovers, provides less assurance for protecting the background and foreground knowledge of partners.

4. Empirical Analysis

4.1. Data

The data for this analysis is drawn from the *Innovation Network Databank (INNET)* of the Center for International Science and Technology Policy at the George Washington University. *INNET* features longitudinal information on strategic alliances, US patents, and business performance for thousands of firms since 1985. For this paper we have used a dataset on research partnerships. The basic information on research partnerships has been drawn from the NCRA-RJV database which records all research joint ventures (RJVs) registered with the US Department of Justice under the auspices of the National Cooperative Research Act of 1984 and its extension, the National Cooperative Production and Research Act of 1993. The NCRA-RJV database provides information on the alliance including title, announcement date, technology classification, and the number and names of participants, as well as information on the identified participants such as SIC codes, name, nation, parent firms, etc.

We started with fifteen years of data of registered RJVs (1985-1999). Figure 1 shows new RJV registrations during this time period, adding up to a total of 796 ventures. Table 1 classifies these ventures by broad technological area. The individual participants from industry in these joint ventures are identified by cross checking with commercially available business databases, mainly CompuStat (publicly-traded firms in the United States) and CorpTech (high-tech firms based in the United States). Table 2 indicates the intensity of activity of individual identified organizations in these ventures (mainly companies and universities) pointing to the fact that, although the majority of the entities have participated only once, a good number have participated repeatedly.

[FIGURE 1 AND TABLES 1-2 ABOUT HERE]

This dataset was subsequently "merged" with the NBER patent database (Hall et al., 2001) which allocates all US patents granted between 1963 and 1999 to inventor organizations and individuals. This merging identified 2,435 entities that have participated in at least one RJV and have obtained at least one patent during this time period. We then chose the firms that had declared at least one SIC code and for which we had longitudinal business performance indicators available from CompuStat. The process left us with 359 firms for the period 1989-1999. They cover a mixture of manufacturing and service sectors (Table 3). These 359 firms – publicly traded in the United States, participating in at least one RJV, and registering at least one patent, registering at least one SIC code to describe their commercial activities, and reporting R&D and sales information consistently during the investigated time period – make up our final sample of RJV participants.

[TABLE 3 ABOUT HERE]

This data sample was then used to construct a panel in which the unit of observation is the unique firm *i* – firm *j* pair, or dyad. For each year, the dyad data is constructed as follows: f*1*~f*2*, f*1*~f*3*,…, f*1*~f*n*; f*2*~f*3*,…, f*2*~f*n*; f*n-1*~f*n*, where f*1*=firm *1*,…, f*n*=firm *n*. There are *nCn-1* dyads in each year. With *n*=359, this translates into 64,291 dyads in each year or 706,801 dyads across the whole time period of 1989-1999.

4.2. Model Specification

We use a random effects probit model to estimate the likelihood that firm *i* will partner with firm *j* in year *t*. Let:

$$P_{ij} = F\,[Z(i,j), N(i,j), Y(i), Y(j), L(I), L(J)]\ , \qquad (1)$$

where

P_{ij} = probability that firms *i* and *j* will meet in a research partnership in time period t.

F = cumulative probability function.

I = primary industry of firm *i*.

J = primary industry of firm *j*.

Z(i,j) = vector of proxies of resource/market interdependencies between firms *i* and *j*.

N(i,j) = vector of network relationships between firms *i* and *j*.

Y(i) = vector of characteristics of firm *i*.

Y(j) = vector of characteristics of firm *j*.

L(I) = vector of market and technological characteristics of industry *I*.

L(J) = vector of market and technological characteristics of industry *J*.

Dependent Variable

$\textbf{\textit{COLLABORATE}}_{ij}$ = 1 if firm *i* and firm *j* met in a research partnership in year *t*;
= 0 otherwise.

Independent Variables

A. Resource/market interdependence Z(i,j).

The ideal match of partners maximizes benefits to collaboration and minimizes costs (Gomes-Casseres, 1993). To maximize benefits, partners must have complementary assets and objectives. They may, for example, have expertise in different, but commercially linked, technologies, or they may specialize in different parts of the value chain. Such differences create value. To minimize costs, however, firms may have good reasons to ally with like-minded partners. Partners that share common goals and strategies should incur lower costs in managing collaboration achieved by decreasing the number of disagreements on market strategy, technology designs, and decision-making processes. In addition, resource similarity facilitates learning: the demands of the technology absorption process are such that a partner must have considerable in-house technical expertise that complements the technology development activities of the alliance (Cohen and Levinthal, 1989).

TECHPROXIMITY$_{ij}$ = degree of similarity in the technological profile of firms *i* and *j* in year *t*.

The technological proximity between two firms *i* and *j* can be measured as their "distance" in "technology space", approximated here by the degree of similarity in their patent portfolios, used as a proxy for technological profile. Patent portfolio similarity is approximated here by an angle between the two firms' patent technology vectors, following Jaffe (1986). (See the Appendix for detailed definition). The technological categories are as defined in Hall et al. (2001); thirty-six patent subcategories are used. The patents obtained from 1969 up the year prior to t are cumulatively counted. When the technology portfolios of firms *i* and *j* are identical, TECHPROXIMITY$_{ij}$ takes the value of 1. When the technology portfolios are completely different, it takes the value of 0.

The resource-based view of the firm (Mowery et al, 1998) would have us expect a nonlinear effect of TECHPROXIMITY$_{ij}$ on the probability that firms *i* and *j* collaborate. Although some degree of technological overlap seems necessary to support a successful alliance, too much overlap yields diminishing and perhaps negative returns: the chances for learning are minimized whereas the chances to lose valuable information to close competitors are maximized. On this basis, we would expect TECHPROXIMITY$_{ij}$ to be a positive factor in partner choice for low to moderate levels of overlap, turning negative at higher levels of overlap.

R&DSPILLOVER$_{ij}$ = *TECHPROXIMITY$_{ij}$ x R&D$_j$*

R&D spillovers have been identified in the economic literature as an important incentive to collaborate (Branstetter and Sakakibara, 1998; d'Aspremont and Jacquemin, 1988; Kamien et al., 1992). Other things being equal, firm *i* will receive more R&D spillovers from firm *j* the larger the R&D budget and the closer the research program of firm *j* is to that of firm *i*. The similarity of research programs can be approximated by the

$TECHPROXIMITY_{ij}$ coefficient. The product of this coefficient and the R&D expenditure of firm *j* will indicate the "effective" spillover firm *i* can expect. A positive sign for $R\&DSPILLOVER_{ij}$ is anticipated.

MARKETPROXIMITY$_{ij}$ = degree of similarity in the market profile of firms *i* and *j*.

The market proximity between firm *i* and firm *j* is calculated the same way to technological proximity except that we now use firms' industry portfolios (primary and secondary SIC codes) instead of patent portfolios. $MARKETPROXIMITY_{ij}$ takes a value between 0 and 1: higher values represent more proximate firms.

Prospective alliance participants are typically loath to discuss their secrets with direct competitors. They also try to avoid collaborating with firms with similar market profile due to the high potential for creating strong competitors (Gomes-Casseres, 1993). On the other hand, market profile similarity implies lower transaction costs. The expected sign for $MARKETPROXIMITY_{ij}$ is ambiguous.

B. Network relationship N(i,j).

While resource and market interdependencies can be important explanatory factors of tie formation between some firms, they may not adequately account for alliance formation (Gulati, 1998). After all, not all opportunities to share interdependencies result in alliances, implying that the conditions for mutual economic advantage are necessary but not sufficient for the formation of an alliance between two firms. The problem with accounts of alliance formation focusing solely on interdependencies is that they ignore the social context in which firms learn about partnering opportunities, overcome hesitations to participate, and partnerships emerge (Granovetter, 1985). Firms rely on existing networks for information regarding new opportunities, for information regarding the reliability and reputation of prospective partners, and for safeguards against opportunistic behavior. Network embeddedness thus becomes an important factor influencing the proclivity of firms to enter alliances. There has been significant evidence of the increased likelihood of firms to enter alliances the more centrally situated they are in the network or the larger their prior experience (Gulati, 1998; Stuart and Podolny, 1996; Powell, Koput and Smith-Doer, 1996).

We built up two types of networks. The knowledge network is formed on the basis of patent citations cumulatively from 1975 up to each observation year. The alliance network is formed on the basis of firm RJV participation cumulatively starting at 1985 among the 2,435 entities that are identified in the merged database. We build the network on the basis of the whole set of entities found in the merged database, expecting thus to capture the overall network embeddedness of the 359 firms under investigation.

FAMILIARITY$_{ij}$ = 1 if firm *i* and firm *j* have collaborated in one or more RJVs initiated before year *t*,

= 0 otherwise.

Familiarity between partners through prior interaction typically lowers the costs of collaboration in terms of gathering information about the other party, bargaining, writing a contract, and enforcing it. Trust displaces a lot of these costs (Gulati, 1995). Repeated contracts with the same partner will build confidence in each partner for the other and will lower the transaction costs of the collaborative agreement. A positive sign for FAMILIARITY_{ij} is expected.

PATENTCENTRALITY$_{ij}$ = joint patent centrality of firms *i* and *j* in year *t*.

The normalized centrality of a firm in the knowledge network (built on patent citations) in year *t* is calculated on the basis of the cumulative patent pool from 1975 to year *t-1*. Joint centrality is simply the average between the two firms' centrality values, which is used to measure the firms' position in the network. We use betweenness centrality to build this measure (see the Appendix for a definition of betweenness centrality). Larger values indicate higher degree of centrality of the two firms as a set in the knowledge network. Considering patent centrality as a mechanism to gain reputation for technical competency and make a firm more desirable as a partner leads to an expectation of a positive influence of $\text{PATENTCENTRALITY}_{ij}$

JOINTCENTRALITY$_{ij}$ = joint centrality of firms *i* and *j* in the alliance network in year *t*.

The normalized centrality of a firm in the alliance network in year *t* is calculated on the basis of the cumulative alliance (RJV) pool from 1985 to year *t-1*. Joint centrality is the average between the two firms' centrality values. Larger values indicate higher degree of centrality of the two firms as a set in the alliance network. We use betweenness centrality to build this variable. On the basis of prior evidence that more central firms are more likely to engage in new alliances, one would expect an increased probability that more central firms will meet each other in new alliances. A positive sign for $JOINTCENTRALITY_{ij}$ is anticipated.

C. Controls

Five sets of control variables are used: the characteristics of each firm in the dyad; the characteristics of the primary industry of each firm; and temporal effects.

(C1) Characteristics of firm i, Y(i)

$\boldsymbol{SALES_i}$ = sales of firm *i* in year *t*.

Sales figures have been used as proxy for firm size. This variable controls for unobservable size effects such as the attractiveness of a firm as a partner because of its internal financial capability and anticipated scale economies in R&D. The expected sign for $SALES_i$ is positive.

$\boldsymbol{ALLEXPERIENCE_i}$ = cumulative number of past alliances entered by firm *i* over the five years prior to year *t*.
= 0 otherwise.

The experience of a firm with RJVs is used here to control for unobserved firm-level factors such as firm strategy. The expected sign of $ALLEXPERIENCE_i$ is positive.

(C2) Characteristics of firm j, Y(j)

$\boldsymbol{SALES_i}$ = sales of firm *j* in year *t*.

$ALLEXPERIENCE_j$ = cumulative number of past alliances entered by firm *j* over the five years prior to year *t*.

= 0 otherwise.

(C3) Characteristics of industry I, L(I)

$GROWTH_I$ = growth rate of primary industry *I* of firm *i* in year *t*.

Rapid market growth creates incentives for expansion, potentially achieved through collaboration. Moreover, even in cases where the firm fears making potential competitors through collaboration, the effect of rent dissipation due to increased competition with new entrants will be minimized by high growth: the higher the growth rate of industry output, ceteris paribus, the less an entrant's supply will depress industry price and output (Orr, 1974). Accordingly, firms will have a better incentive to collaborate in rapidly growing sectors. A positive sign for $GROWTH_I$ is expected.

$INDUSTRY\ PATENT_I$ = Patent / R&D expenditures of primary industry *I* of firm *i* in year *t* (propensity to patent).

Strong intellectual property rights (IPR) protection creates a sense of security. The stronger IPR is in an industry, the better the ability of a partner to maintain control of both background and foreground knowledge in a collaborative agreement, ceteris paribus. A weak IPR regime exacerbates the appropriability problem, always present in R&D-intensive activities. On the other hand, most alliances in our dataset are in industries where the IPR systems have not been traditionally very strong (Table 1). It has been argued strongly in the economic literature that weak appropriability is one of the major factors inducing firms to collaborate with others to share the risks of creating new technologies.[5] Patent-intensity is used here as a proxy of the strength of the intellectual property protection system as perceived by the members of an industry. The expected sign for $INDUSTRY\ PATENT_I$ is ambiguous.

[5] See Caloghirou et al. (2003), Hagedoorn, Link and Vonortas (2000), and Vonortas (1997) for extensive surveys of this literature.

COMPLEXITY$_I$ = 1 if industry *I* is a complex product industry;

= 0 otherwise.

Cohen et al. (2000, 2002) distinguish between “complex” and “discrete” (simple) product industries based on whether a new product incorporates numerous separately patentable elements or relatively few. For example, electronic products typically are comprised of a relatively large number of patentable elements, and thus characterized as complex. In contrast, new drugs or chemicals are comprised of a relatively discrete number of patentable elements (often a single formula) (Rycroft and Kash, 1999). As a result, simple products can be better protected (strong IPR) whereas complex products may be easier to invent around. Following Cohen et al. (2002), we use SIC 35 as a crude cut-off point between complex product industries (35 and above) and simple product industries (below 35). As defined, simple product industries include ferrous and non-ferrous metals, chemicals, petrochemicals, drugs, food, tobacco, and so forth. Complex product industries include machinery, computers, electrical equipment, scientific instruments, and all kinds of services.[6]

This variable can be considered as a second proxy for the strength of the IPR regime in an industry. Similar arguments to those above apply. Better IPR protection (easier to enforce, less expensive) can raise the prospects of collaboration. The opposite could also be argued if collaboration is considered as a mechanism to undertake imperfectly appropriable activities. The sign for COMPLEXITY$_I$ is ambiguous.

GPT$_I$ = 1 if industry *I* can be described as ICT, biotechnology, or advanced materials;

= 0 otherwise.

Information and communication technologies (ICT), biotechnology, and advanced materials have “infrastructural” characteristics (general purpose technologies). They have penetrated throughout the economy during the past two to three decades and have thus dramatically altered the basic meaning of high technology: rather than referring to the

[6] The inclusion of services in the complex technology category is important. The penetration of information technology has gradually shifted the locus of high technology production from exclusively manufacturing to a combination of manufacturing and service industries (Hauknes 1998; Leech, et al. 1998; OECD 2000). The share of service sectors in alliances has increased very significantly (Kang and Sakai, 2000).

output of R&D-intensive industries, high tech is now argued to indicate a style of work applicable to just about any business (Branscomb and Florida 1998; Porter 1998). GPTs, and especially ICT, have predominated alliances since the early 1980s (Hagedoorn, 2001). We used CorpTech's industry classification (Table 1) and included the following industries in GPTs: Biotechnology, Computer Hardware, Advanced Materials, Computer Software, and Telecommunications. A positive sign of GPT_I is anticipated.

(C4) Characteristics of industry J, L(J)

$GROWTH_J$ = growth rate of primary industry *J* of firm *j* at *t*.

$INDUSTRY\ PATENT_J$ = Patent / R&D expenditures of primary industry *J* of firm *j* at *t*.

$COMPLEXITY_J$ = 1 if industry *J* is a complex product industry;
= 0 otherwise.

GPT_J = 1 if industry *J* can be described as ICT, biotechnology, or advanced materials;
= 0 otherwise.

(C5) Temporal effects

Finally, to control for unobserved temporal factors we use ten dummy variables, TEMP1-TEMP10, one less than the number of years in the panel.

The Appendix provides additional detail regarding the construction of the more synthetic variables. Tables 4 and 5 provide descriptive statistics of the variables and the correlation matrix respectively. Table 6 shows the annual distribution of observed and not-observed dyads. Table 7 provides the distribution of firms on the basis of the COMPLEXITY and the GPT variables.

[TABLES 4, 5, 6, 7 ABOUT HERE]

5. Results

5.1. Estimation

Table 8 presents the estimation results. Four models are presented with different sets of explanatory variables. Model I uses the variables indicating the relationship (resource and market interdependencies) between firms *i* and *j* (*Z(i,j)*). Model II adds the network relationships between firms *i* and *j* (*Z(i,j)+N(i,j)*). Model III adds the characteristics of the two firms (*Z(i,j)+N(i,j)+Y(i)+* (*Y(j)*). Finally, model IV adds the characteristics of the primary sectors of the two firms (*Z(i,j)+N(i,j)+Y(i)+* (*Y(j)+L(I)+ L(J)*) (complete model).

[TABLE 8 ABOUT HERE]

Table 9 summarizes the estimation results for the complete model IV and juxtaposes the sign and significance of the coefficients to our expectations. The Table also categorizes the explanatory variables into four sets: resource and market interdependence relationship between firms *i* and *j*; network relationship between firms *i* and *j*; characteristics of firms *i* and *j*; and characteristics of the primary industries of firms *i* and *j*.

[TABLE 9 ABOUT HERE]

The estimation results are quite strong. Sixteen out of eighteen explanatory variables are statistically significant. Specifically, the first three sets of explanatory variables are fully statistically significant, including those that describe the resource/market interdependence between the cooperating firms, the network relationship among them, and the characteristics of each firm. The two non-significant variables belong to the fourth set describing the characteristics of the primary industries of the cooperating firms: the non-performing variables refer to the growth rate of the respective primary sectors. Moreover, all statistically significant variables have the anticipated signs. No signs reverse across models and the size of the coefficients remains relatively stable.

5.2. Discussion

The most important explanatory factors of the probability that two firms will engage in a research partnership are the relationship between the two firms (resource and market interdependencies, network relationship) and the characteristics of each firm. All ten variables in these three sets are highly statistically significant (p=0.001 level). The joint centrality of the two firms in the alliance network is significant at the p=0.05 level.[7] According to Tables 8 and 9, firms are more likely to collaborate the closer they are in terms of both technological and market profiles, the higher the expected knowledge spillovers among them, the more familiar they are with each other through past interaction, and the more centrally located they are in both the alliance and the knowledge networks. The combination of lower expected transaction costs for the cooperative activity due to similarities in capabilities ($TECHPROXIMITY_{ij}$, $MARKETPROXIMITY_{ij}$), increased trust ($FAMILIARITY_{ij}$, $JOINTCENTRALITY_{ij}$), and higher opportunities for mutual learning ($R\&DSPILLOVER_{ij}$, $PATENTCENTRALITY_{ij}$) are shown to create a strong attraction for firms to collaborate in R&D. The cost incentive for partnering is further reinforced by the significant and positive influence of prior experience with networking ($ALLEXPERIENCE_i$, $ALLEXPERIENCE_j$). Firm size also comes out as a statistically significant factor ($SALES_i$, $SALES_j$): not surprisingly, the chances for two firms to meet in an agreement increases with their size.

Operating in technologically complex sectors ($COMPLEXITY_I$, $COMPLEXITY_J$) and being identified with general purpose technologies (GPT_I, GPT_J) does raise the chance that two firms will meet in R&D partnerships, echoing the observations that ICT has dominated alliances of this kind. Operating in industries with high propensity to

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[7] In fact, $JOINTCENTRALITY_{ij}$ is the only variable whose level of significance drops from p=0.001 to p=0.05 from model II to model IV.

patent (INDUSTRY $PATENT_I$, INDUSTRY $PATENT_J$), however, seems to operate as an impediment to R&D partnering. Finally, rapid growth in the main sector of the firm seems, if anything, to affect R&D partnering negatively; but its estimated effect is not statistically significant.[8]

These results support all three hypotheses laid out earlier in the paper. The attraction of 'localized' R&D cooperation comes through clearly: similarities in both technological capabilities and market specialization and possibilities for higher knowledge spillovers positively affect the likelihood that two firms collaborate in R&D. The closer two firms are, the lesser the transaction costs of collaborating and the higher the ability to learn from the partner. The importance of value creation as a factor weighing in one's decision for choosing a partner also comes through clearly: repeated R&D collaboration between the partners and mutual central positions in the alliance network build trust and social control mechanisms that decrease the transaction costs associated with any particular deal. Combined to expectations for increased learning due to the partner's more central position in the knowledge network, these factors further enhance the incentives to work with the specific organization. Finally, firms tend to collaborate the more experienced they are in networking, the more complex their products are, and the more they deal with general purpose technologies.

An interesting outcome was the negative estimated correlation between the likelihood of two firms collaborating in R&D and the intensity of patent protection in their primary sectors. Put differently, firms are looking for partners in less well protected industrial environments, everything else remaining the same. This result contradicted expectations in the third hypothesis. While some of the explanation may be attributed to

[8] We suspect that the growth variables – and to some extent the patent intensity variables – did not work as well as expected because we were obliged to use the primary industry of the firms to capture industry-level effects on the incentives of two firms to enter a collaborative agreement. The first best would have been to use the industry in which the specific agreement can be classified in. While this information was available to us, the reason for choosing the primary industry of the firm is that our econometric methodology juxtaposes the dyads which were observed with those which were not: we obviously did not have the industrial classification for non-consummated partnerships. Considering that the collaboration may be in a field different from the partner's primary sector, however, the estimated coefficients may lack the necessary explanatory power. There is no obvious solution to this problem other than choosing a different analytical methodology. We considered such a solution unjustifiable in this case given the strong results we obtain with the remaining, very important variables.

the choice of the sector to focus on[9], we believe that we have here some proof for a phenomenon that others have already discussed for some time. This is the argument advanced by the economic literature on innovation (Levin et al., 1987; Hall and Ziedonis, 2001) and the network literature (Gulati, 1998) that (a) intellectual property protection in the traditional sense may no longer matter that much in R&D-intensive industries and (b) the social trust and control mechanisms developed in a network are largely anticipated to take care of problems of intellectual misappropriation if and when they might arise.

6. Conclusion

This paper has been motivated by an interest in the effects of the knowledge and alliance networks in which firms are embedded on their cost-benefit calculus regarding partner selection for cooperative R&D. The most important explanatory factors of the likelihood that two firms will engage in a research partnership have been shown to be the resource and market interdependencies and network relationship between the two firms, on one hand, and the characteristics of each firm, on the other. Firms are more likely to collaborate the closer they are in terms of both technological and market profiles, the higher the expected knowledge spillovers among them, the more familiar they are with each other through past interaction, and the more centrally located they are in both the alliance and the knowledge networks. The likelihood of partnering also rises with the firms' prior networking experience and with their size.

These results imply that firms prefer not to venture far away in terms of technological and market specialization when choosing research partners. The combination of lower expected transaction costs for the cooperative activity due to similarities in capabilities, increased trust, and better opportunities for learning raises the appeal of a prospective partner. Picking central network players with whom the firm has collaborated before also keeps costs low while reinforcing learning possibilities. Prior networking experience, product complexity, and involvement in general purpose technologies further raise R&D partner attraction. Formal intellectual property protection mechanisms such as patents loose some of their luster in networked environments.

[9] See footnote 8.

These we consider important results with significant strategy and policy implications. For example, if ‘birds of a feather stick together’ in collaborative R&D agreements, some of the discussion about R&D networks as mechanisms to place bets in very risky, very new technology areas may need to be carefully reconsidered. One might think that such an objective would require collaboration between organizations that look and think quite differently. Such alliances would, however, suffer from relatively high transaction costs and potentially low possibilities for internalizing information (learning) which, according to the analysis herein, makes them less attractive to prospective participants. Managers of public programs that promote collaborative R&D need to be aware of the transaction cost and learning sensitivities of likely participants. They may also consider support differentials in proportion to the resource/capability ‘distance’ and lack of familiarity of likely participants with each other and with cooperative research activities altogether.

The limitations of this analysis relate to the size distribution of the firms in our sample and the use of their primary sector for estimating industry effects. The set of examined firms was, by and large, confined to large, publicly traded corporations for which long enough time series of business and R&D performance data is available. A mixture of large and small firms would have been preferable. The use of the firms’ primary sector instead of the sector the alliance classifies in has created the only non-performing variable (industry growth). Unfortunately, neither of these factors could be circumvented as discussed in earlier sections. All in all, we are strongly encouraged by the results and consider further empirical investigation of these issues worthwhile.

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APPENDIX

Complex variable definition, preparation, and data source

TECHPROXIMITY$_{ij}$: The variable is an angle between the two firms' patent profile vectors, following Jaffe (1986). Let *Ei* be firm *i*'s patent profile vector in R^{36}, where 36 is the number of sub-categories defined in Hall, Jaffe, and Trajtenberg (2001). *Ei(k)*, the *k*th element of *Ei*, contains the cumulative number of patents granted to firm *i* in *k*th sub-category from 1969 up to the year prior to the current year. The number of patents is discounted with 15% rate. Then,

$$\textbf{\textit{TECHPROXIMITYij}} = \frac{Ei \cdot Ej}{|\,Ei\,| \cdot |\,Ej\,|}$$

$\mathrm{TECHPROXIMITY}_{ij} = 1$ when *Ei* and *Ej* are identical. $\mathrm{TECHPROXIMITY}_{ij} = 0$ when *Ei* and *Ej* are completely different from each other.

MARKETPROXIMITY$_{ij}$: The variable is an angle between the two firms' market profile vectors based on the firms' primary and secondary SIC codes. Let *Ei* be firm *i*'s market profile vector. *Ei(k)*, the *k*th element of *Ei* is set 1 if firm *i* lists SIC code, k as either its primary or secondary line of business. *Ei(k)* is set 0 otherwise. Then,

$$\textbf{\textit{MARKETPROXIMITYij}} = \frac{Ei \cdot Ej}{|\,Ei\,| \cdot |\,Ej\,|}$$

$\mathrm{MARKETROXIMITY}_{ij} = 1$ when *Ei* and *Ej* are identical. $\mathrm{MARKETPROXIMITY}_{ij} = 0$ when *Ei* and *Ej* are completely different from each other. The data comes from CompuStat,

Description of Networks: Two types of networks are built to capture the firms' network embeddedness: the technology network and the alliance network. In the networks entities are represented by 'nodes' and a connection between two nodes are represented by a 'link'.

The technology network is formed through patent citations cumulatively from 1975 to the current year. 'Self-loops', that is, links to oneself, may happen in the technology network if a firm cites its past patents. 'Self-loops' are eliminated. The technology network originally has a 'direction,' *i.e.* information flows from cited patents to citing patents. We don't take the direction into consideration in the analysis.

The alliance network is formed through the firms' participation in RJVs cumulatively starting from 1985. 'Self-loops' (a firm participates in an RJV multiple times through its divisions or subsidiaries) are eliminated.

One can build the alliance and technology networks either by looking at the relationships among the 359 firms in the sample or by additionally looking at the relationships of these firms with everyone else (2,435 entities are identified in the merged database). We have followed the latter procedure in building the network data for our econometric analysis: the larger network enables us to capture the 359 firms' embeddedness in the overall ~~RJV~~ alliance network.

Betweenness centrality is used to obtain the variables $\boldsymbol{PATENTCENTRALITY_{ij}}$ and $\boldsymbol{JOINTCENTRALITY_{ij}}$. Betweenness centrality of a node (firm) in a network indicates the extent to which the node is *between* the shortest link that connects all other nodes in the network. High betweenness centrality value suggests that the node plays a critical role in communication in the network. Let $G = g_{ij}$ be a matrix representing the total number of the shortest path between nodes i and j. Let $G(k) = g_{ij}(k)$ be the number of geodesics between nodes i and j passing through node k. Then node k's normalized betweenness $C_B(k)$ is given as:

$$\boldsymbol{C_B(k)} = \frac{2}{(n-1)(n-2)} \cdot \sum_{i<j} \frac{g_{ij}(k)}{g_{ij}}$$

where n is the number of nodes. $C_B(k)$ is 1 at maximum when node k is located in the center of a star-shape network. $C_B(k)$ is 0 when node k is located in a peripheral position in the network. We use the algorithm developed by Brandes (2001) in calculating betweenness centrality.

The obvious alternative to betweenness centrality is *degree centrality*, *i.e.* a number of neighboring nodes directly linked to the focused node. It may be obtained much more easily than the betweenness centrality. The problem of degree centrality is, however, that a large degree centrality value doesn't necessarily mean that the node is located in central position in the network; rather, it may be the case that such a node is located in a peripheral position. For example, in the technology network, a firm may have high degree centrality value if its patents cite many other patents but they are cited by only a few.

$\boldsymbol{GROWTH_I}$, $\boldsymbol{GROWTH_J}$: Two-digit level SIC codes are used to classify industries. The annual growth rate of industry I for year t is defined as:

$$\boldsymbol{GROWTH_{I,t}} = \frac{\boldsymbol{GDP_{I,t} - GDP_{I,t-1}}}{\boldsymbol{GDP_{I,t-1}}} \times 100.00$$

where $GDP_{I,t}$ is Industry I's GDP in year t in constant 1996 dollars. The data comes from the Bureau of Economic Analysis (http://www.bea.gov, section 'GDP by Industry').

INDUSTRYPATENT: Industry I 's (2-digit SIC) patent intensity for year t is defined as:

$$\boldsymbol{INDUSTRYPATENT_{I,t}} = \frac{\sum \boldsymbol{Granted\ patents_{I,t}}}{\sum \boldsymbol{R\&D\ expenditure_{I,t}}}$$

where $\Sigma \textit{Granted patents}_{I,t}$ is the sum of patents granted to firms in industry *I* in year *t*, and $\Sigma \textit{R\&D expenditure}_{iI,t}$ is the sum of R&D expenditure of firms in industry *I* in year *t*.

$\boldsymbol{GPT_I}$, $\boldsymbol{GPT_J}$: CorpTech's concordance tables are used to translate 4-digit SIC codes into CorpTech industry codes (see Table 1). We then categorize into general purpose technologies (GPT) the following: Biotechnology, Computer Hardware, Advanced Materials, Computer Software, and Telecommunications.

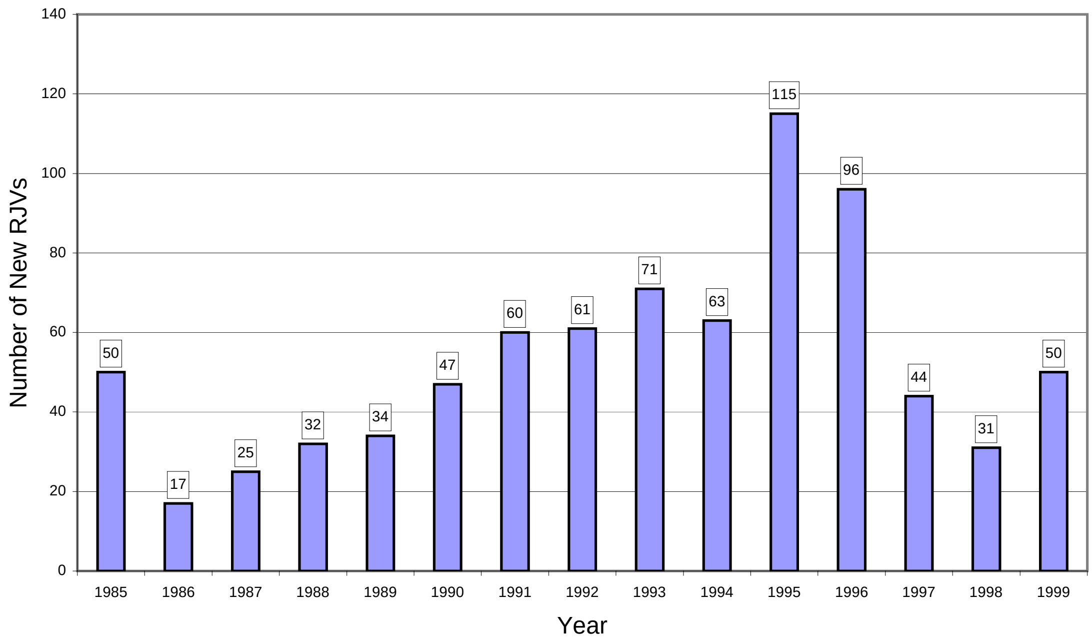

Figure 1. New RJV announcements

Table 1. Primary Technical Areas of RJVs

Technical Area	Number of RJVs
Telecommunication	147
Transportation	75
Advanced materials	73
Environmental	71
Energy	69
Software	65
Subassemblies	50
Chemicals	46
Manufacturing Equip.	40
Test and Measure	34
Photonics	30
Factory automation	29
Computers	21
Biotech	15
Medicals	13
Pharmaceuticals	4
Defense	1
N/A	13
Total	796

Note: This classification method follows the definitions of high-tech industrial activity of the 'Corporate Technologies' database (CorpTech)

Table 2. Cooperative activities of all entities

Number of Memberships	Memberships	Entities	% (Entities)
1	4838	4838	74.2
2	1730	865	13.3
3	888	296	4.5
4	532	133	2.0
5	430	86	1.3
6 to 10	1127	146	2.2
11 to 20	1281	90	1.4
21 to 50	1260	40	0.6
More than 50	1933	23	0.4
Total Memberships	14019		
Total Entities		6517	100.0

Note: Memberships count every mention of identified organizations in the database. Entities count individual organizations only once, following aggregation of divisions, subsidiaries etc into the single holding company.

Table 3. Distribution of firms by 2-digit SIC code

2-digit SIC code	Description	Number of firms
36	Electronics & Other Electric Equip. & Components, except Computer Equip.	85
35	Industrial & Commercial Machinery & Computer Equip.	66
28	Chemical & Allied Products	43
38	Instruments & Related Products	36
73	Business Services	29
37	Transportation Equip.	21
33	Primary Metal Industries	13
34	Fabricated Metal Products, except Machinery & Transportation Equip.	10
29	Petroleum Refining	8
32	Stone, Clay, Glass, & Concrete Products	6
30	Rubber & Miscellaneous Plastics Products	5
48	Communications	5
13	Oil & Gas Extraction	4
20	Food & Kindred Products	4
26	Paper & Allied Products	4
50	Wholesale Trade- Durable Goods	4
87	Engineering & Management Services	4
39	Miscellaneous Manufacturing Industries	3
51	Wholesale Trade- Non-durable Goods	2
14	Nonmetallic Minerals, except Fuel	1
21	Tobacco Products	1
22	Textile Mill Products	1
24	Lumber & Wood Products, except Furniture	1
25	Furniture & Fixtures	1
53	General Merchandise Stores	1
80	Health Services	1
	Total	359

Table 4. Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
$COLLABORATE_{ij}$	1.90e-02	1.37e-01	0	1
$TECHPROXIMITY_{ij}$	1.43e-01	2.11e-01	0	1
$R\&DSPILLOVER_{ij}$	3.45e+02	2.23e+03	0	8.01e+04
$MARKETPROXIMITY_{ij}$	3.35e-02	1.17e-01	0	1
$FAMILIARITY_{ij}$	1.37e-01	3.43e-01	0	1
$PATENTCENTRALITY_{ij}$	2.13e-03	4.97e-03	0	6.34e-02
$JOINTCENTRALITY_{ij}$	1.51e-03	3.53e-03	0	5.17e-02
$SALES_{i}$ ($M)	8.29e+03	1.89e+04	0	1.73e+05
$SALES_{j}$ ($M)	6.25e+03	1.48e+04	0	1.73e+05
$ALLEXPERIENCE_{i}$	4.28	9.85	0	9.70e+01
$ALLEXPERIENCE_{j}$	3.30	7.87	0	9.70e+01
$GROWTH_{I}$ (%)	5.72	8.55	-4.28e+01	4.90e+01
$GROWTH_{J}$ (%)	6.19	8.89	-4.28e+01	4.90e+01
$INDUSTRYPATENT_{I}$	2.21e-01	1.59e-01	0	3.02
$INDUSTRYPATENT_{J}$	2.30e-01	1.54e-01	0	3.02
$COMPLEXITY_{I}$	6.91e-01	4.62e-01	0	1
$COMPLEXITY_{J}$	7.41e-01	4.38e-01	0	1
GPT_{I}	3.92e-01	4.88e-01	0	1
GPT_{J}	5.10e-01	5.00e-01	0	1

Table 5. Correlation Matrix

	Variable	1	2	3	4	5	6	7	8	9
1	TECHPROXIMITY$_{ij}$	1								
2	R&DSPILLOVER$_{ij}$	-0.05	1							
3	MARKETPROXIMITY$_{ij}$	0.2331	0.018	1						
4	FAMILIARITY$_{ij}$	0.2543	0.0997	0.1578	1					
5	PATENTCENTRALITY$_{ij}$	0.2585	-0.0154	0.0037	0.3091	1				
6	JOINTCENTRALITY$_{ij}$	0.1708	0.1169	0.0164	0.4626	0.5204	1			
7	SALES$_{i}$	0.1124	-0.014	-0.0223	0.2073	0.396	0.4047	1		
8	SALES$_{j}$	0.1122	0.223	-0.015	0.2111	0.35	0.3395	0.0062	1	
9	ALLEXPERIENCE$_{i}$	0.1225	-0.011	0.0084	0.2366	0.3616	0.4755	0.708	0.0091	1
10	ALLEXPERIENCE$_{j}$	0.1203	0.1612	0.0143	0.2764	0.2999	0.4517	0.0034	0.5986	0.0066
11	GROWTH$_{I}$	0.0556	-0.0141	0.0675	0.0558	0.0213	-0.0055	-0.0401	0.0218	0.0021
12	GROWTH$_{J}$	0.0326	0.0073	0.0518	0.0472	0.0229	0.0221	0.0237	-0.0402	0.0306
13	INDUSTRYPATENT$_{I}$	-0.0668	0.0156	-0.0314	-0.0862	-0.0733	-0.0844	-0.2139	-0.018	-0.1639
14	INDUSTRYPATENT$_{J}$	-0.0494	-0.0697	-0.0421	-0.0943	-0.051	-0.0858	-0.0169	-0.2025	-0.0242
15	COMPLEXITY$_{I}$	-0.0031	0.0193	0.1038	0.0933	0.0236	-0.0057	-0.0425	-0.0022	-0.0639
16	COMPLEXITY$_{J}$	-0.0358	0.0118	0.0877	0.0758	0.0019	-0.0077	-0.004	-0.0881	-0.0024
17	GPT$_{I}$	0.0174	-0.0079	0.1265	0.0591	0.0249	0.0627	-0.058	-0.0144	0.0144
18	GPT$_{J}$	-0.043	0.0569	0.1046	0.0306	-0.0063	0.0051	-0.0012	-0.0985	-0.0036

	Variable	10	11	12	13	14	15	16	17	18
10	ALLEXPERIENCE$_{j}$	1								
11	GROWTH$_{I}$	0.0237	1							
12	GROWTH$_{J}$	-0.0012	0.2006	1						
13	INDUSTRYPATENT$_{I}$	-0.0192	-0.3326	-0.102	1					
14	INDUSTRYPATENT$_{J}$	-0.128	-0.1035	-0.4257	0.0856	1				
15	COMPLEXITY$_{I}$	-0.0035	0.2775	-0.0004	0.015	0.002	1			
16	COMPLEXITY$_{J}$	-0.0302	0.002	0.2726	0.0011	-0.0162	0.0003	1		
17	GPT$_{I}$	-0.0104	0.1705	0.0011	-0.0273	0.0072	0.206	0.0097	1	
18	GPT$_{J}$	-0.0131	0.0042	0.251	0.0001	-0.0966	0.0025	0.2583	0.0113	1

Table 6. Annual Distribution of Dyads

Year	1989	1990	1991	1992	1993	1994
Observed	1,970	536	1,224	794	3,033	923
Not observed	62,291	63,725	63,037	63,467	61,228	63,338
Total	64,261	64,261	64,261	64,261	64,261	64,261

Year	1995	1996	1997	1998	1999	Total	(%)
Observed	1,441	1,073	1,301	242	921	13,458	(1.9%)
Not observed	62,820	63,188	62,960	64,019	63,340	693,413	(98.1%)
Total	64,261	64,261	64,261	64,261	64,261	706,871	(100%)

Table 7. Firm Distribution by Complex and General Purpose Technology

Technology type	non-GPT	GPT	Total
Non-Complex Technology	75	27	102
Complex Technology	122	135	257
Total	197	162	359

Table 8. Random-effects Panel Probit Estimates of the Likelihood of Collaboration between firms *i* and *j* during 1989-1999.

Variable	Model I	Model II	Model III	Model IV
TECHPROXIMITY	1.23***	7.79e-01***	7.75e-01***	8.29e-01***
	(2.42e-02)	(2.08e-02)	(2.08e-02)	(2.06e-02)
R&DSPILLOVER	3.38e-05***	2.88e-05***	2.57e-05***	2.24e-05***
	(1.61e-06)	(1.32e-06)	(1.36e-06)	(1.36e-06)
MARKETPROXIMITY	1.56***	1.18***	1.21***	9.06e-01***
	(4.59e-02)	(3.38e-02)	(3.38e-02)	(3.33e-02)
FAMILIARITY	-	6.12e-01***	5.99e-01***	5.60e-01***
	(-)	(1.32e-02)	(1.31e-02)	(1.32e-02)
PATENTCENTRALITY	-	2.33e+01***	1.69e+01***	1.31e+01***
	(-)	(8.43e-01)	(8.78e-01)	(8.66e-01)
JOINTCENTRALITY	-	2.41e+01***	4.56**	2.77*
	(-)	(1.19)	(1.39)	(1.38)
$SALES_i$	-	-	3.13e-06***	3.38e-06***
	(-)	(-)	(2.98e-07)	(3.03e-07)
$SALES_j$	-	-	1.02e-06**	2.22e-06***
	(-)	(-)	(3.33e-07)	(3.36e-07)
$ALLEXPERIENCE_i$	-	-	5.90e-03***	7.59e-03***
	(-)	(-)	(5.64e-04)	(5.70e-04)
$ALLEXPERIENCE_j$	-	-	1.23e-02***	1.32e-02***
	(-)	(-)	(5.96e-04)	(5.90e-04)
$GROWTH_I$	-	-	-	-1.66e-04
	(-)	(-)	(-)	(7.06e-04)
$GROWTH_J$	-	-	-	-2.76e-04
	(-)	(-)	(-)	(7.24e-04)
$INDUSTRYPATENT_I$	-	-	-	-1.06e-01**
	(-)	(-)	(-)	(3.97e-02)
$INDUSTRYPATENT_J$	-	-	-	-7.06e-02♣
	(-)	(-)	(-)	(4.21e-02)
$COMPLEXITY_I$	-	-	-	2.05e-01***
	(-)	(-)	(-)	(1.37e-02)
$COMPLEXITY_J$	-	-	-	1.69e-01***
	(-)	(-)	(-)	(1.44e-02)
GPT_I	-	-	-	2.09e-01***
	(-)	(-)	(-)	(1.12e-02)
GPT_J	-	-	-	1.86e-01***
	(-)	(-)	(-)	(1.16e-02)
Coefficient	-2.83***	-2.57***	-2.60***	-2.98***
	(1.85e-02)	(1.48e-02)	(1.50e-02)	(2.77e-02)
Observation	706871	706871	706871	706871
Log likelihood	-52127.575	-49575.895	-49137.356	-48411.613

Standard errors in parentheses, ♣: p<0.1, *: p<0.05, **: p<0.01, ***: p<0.001.

Table 9. Expected and Estimated Results (random-effects panel probit estimates)

Variable category	Variable	Expected sign	Regression results
Resource/Market interdependence	$TECHPROXIMITY_{ij}$	+	+***
	$R\&DSPILLOVER_{ij}$	+	+***
	$MARKETPROXIMITY_{ij}$	?	+***
Network relationship	$FAMILIARITY_{ij}$	+	+***
	$PATENTCENTRALITY_{ij}$	+	+***
	$RJVCENTRALIY_{ij}$	+	+*
Firm characteristics	$SALES_i$	+	+***
	$SALES_j$	+	+***
	$ALLEXPERIENCE_i$	+	+***
	$ALLEXPERIENCE_j$	+	+***
Industry characteristics	$GROWTH_I$	+	-
	$GROWTH_J$	+	-
	INDUSTRY $PATENT_I$	?	-**
	INDUSTRY $PATENT_J$	?	-♣
	$COMPLEXITY_I$	?	+***
	$COMPLEXITY_J$	?	+***
	GPT_I	+	+***
	GPT_J	+	+***

Standard errors in parentheses, ♣: p<0.1, *: p<0.05, **: p<0.01, ***: p<0.001.