



**DIME Second Research Activity Line (RAL2)
The Creation, Accumulation and Exchange of Knowledge
in Networks, Sectors and Regions**

Working papers Series

Paper to be presented at the DRUID Summer Conference 2006 on

**KNOWLEDGE, INNOVATION AND COMPETITIVENESS:
DYNAMICS OF
FIRMS, NETWORKS, REGIONS AND INSTITUTIONS**

Copenhagen, Denmark, June 18-20, 2006

Track: Networks and Knowledge Creation, Accumulation and Exchange

THE STRENGTH OF R&D NETWORK TIES IN HIGH-TECH INDUSTRIES –
A MULTI-DIMENSIONAL ANALYSIS OF THE EFFECTS OF TIE STRENGTH
ON TECHNOLOGICAL PERFORMANCE

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April 11th, 2006

Keywords: R&D partnerships, networks, tie strength, innovative performance

JEL codes: L14, O30, D83, D85, A14.

The authors would like to thank participants at the British Academy of Management conference 2004, and seminars at Copenhagen Business School, University of Kentucky, Maastricht University, Oxford University, University of Sussex, Tilburg University and Seok-Woo Kwon for their suggestions and comments on earlier versions of this paper.

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Abstract

This paper studies the effect of inter-firm R&D network ties on the technological performance of companies in high-tech industries. Tie strength is analysed through a multidimensional perspective. We find that strong ties in terms of the dimensions time and depth, measured by length and multitude of partnerships, degree of cooperation and similarity of ties, do indeed improve technological performance. However, our findings on cultural closeness support a weak ties perspective. Our research suggests that a combination of stronger and weaker R&D ties, with elements of both social embeddedness and international diversity, is most beneficial for the technological performance of companies.

INTRODUCTION

Network ties, whether at the level of individuals or at the level of companies, can be described in various ways but central to many contributions to social network theory is the concept of tie strength (see for instance Granovetter, 1973; Krackhardt, 1992; Rowley, Behrens and Krackhardt, 2000). The analysis of the effect of tie strength, in terms of weak ties or strong ties, based on Granovetter's (1973) seminal contribution, has had a profound impact on the current management and organization literature. So far most of this literature has analysed these network ties in the context of individuals and small groups behaviour, see Perry-Smith and Shalley (2003) for a review of a large part of this literature. Important topics that feature in this body of literature refer to a detailed analysis of the development of inter-personal relationships and group cohesion in a network setting (Nelson, 1989; Krackhardt, 1992). Other relevant subjects deal with inter-personal information sharing in social networks (Granovetter, 1973; Hansen, 1999; Ibarra and Andrews, 1993; Krackhardt, 1992; Shah, 1998; Weimann, 1983) and creativity development, innovation and small group behaviour (Hansen, 1999; Perry-Smith and Shalley, 2003). Although social network theory has also influenced the analysis of the behaviour of companies and other organisations, compared to intra-organizational studies, there is still a relatively small number of studies that concentrate specifically on the effect of strong and weak ties in an inter-organizational network setting (see the literature discussed in the next section).

In the following we will attempt to contribute to the body of literature on inter-organizational network ties, in an analysis of the effect of strong or weak ties on the technological performance of companies in high-tech industries. A central question in that context is whether companies in high-tech industries, such as pharmaceuticals, computers, semiconductors, and telecom, should forge strong or weak ties with other companies through R&D partnerships that can improve their technological performance. As demonstrated in a

number of studies, high-tech industries are a major area of industrial activity where companies forge an increasing number of partnerships (Chung, Singh and Lee, 2000; Gomes-Casseres, 1996; Hagedoorn, 2002). It is also in these industries, where a large number of companies are engaged in joint R&D through a variety of different modes of R&D partnerships (Hagedoorn 1993; Soh, 2003).

When companies engage in R&D partnerships, the strength of their network ties through these partnerships emerges as an important topic when they face a range of strategic considerations regarding the partners with whom they might cooperate. Major strategic concerns focus on which companies to collaborate with, what sort of ties to build, how close a partner should be, how long the partnership or the collaboration should last, how frequent partners should engage in different partnerships over a longer period of time? As explained in more detail below, these different questions already indicate that network ties might refer to a multi-faceted phenomenon, although much of the current literature on inter-organizational ties has taken a much more one-dimensional perspective. Following some recent suggestions for a more multidimensional approach (for instance McEvily and Zaheer, 1999) we will analyse the effect of inter-firm network ties from a multidimensional perspective that returns to some basic elements of the contribution by Granovetter (Granovetter, 1973).

The empirical setting of our study is a large international population of more than three thousand R&D partnerships, established in the four high-tech industries, introduced in the above, during the period 1990-2000. These R&D partnerships are sponsored by nearly 1700 companies from 39 countries. So far most studies on the effect of inter-organizational network strength consider only domestic, in particular US, ties within one or two industries. Also, with the exception of a few studies (for instance Bruederl and Preisendoerfer, 1998 and Rao, Davis and Ward, 2000) most other contributions refer to relatively small data sets.

In the next section, we will first discuss the current literature on inter-organizational network ties, considering in particular the pro's and con's of strong or weak ties that might benefit companies that engage in inter-firm partnering. For obvious reasons, our theoretical considerations will focus on the expected effect that network tie strength might have on the technological performance of companies that engage in R&D partnerships. This is followed by a discussion of the possible shortcomings of a more narrow understanding of the concept of tie strength and the possible benefits of a broader multidimensional perception. After explaining the benefits of a multidimensional measurement of tie strength, major elements of this approach are placed in the context of the current literature on inter-firm partnership formation. The section on the research methods provides some details on the population that we analyze and our data sources, it also introduces the variables used in the empirical analysis. This is followed by a brief outline of the results, which are discussed further in the last section, in the context of both the theoretical and methodological implications of our study.

THEORETICAL BACKGROUND

In Granovetter's original contribution to social network analysis (Granovetter, 1973), network ties were analyzed in terms of a movement along a continuum from weak to strong ties, in which this continuum is a function of the amount of time, emotional intensity, intimacy, and reciprocity within a relationship between network actors. In addition to this, Granovetter's differentiation of network ties also refers to the degree of similarity or dissimilarity of social circles in which a relationship is established (Granovetter, 1973). The basic argument of Granovetter was that a weak tie, through the combined effect of these different dimensions of tie strength, generates more relevant new information to a network actor than a strong tie,

because a weak tie is more likely to generate a non-redundant connection between different social circles or local networks.

This non-redundant connection, also known as a structural bridge, is a unique direct tie between two networks, where no other direct or indirect ties connect the two local networks that surround actors (Burt, 1992; Granovetter, 1973 and 1982; Perry Smith and Shalley, 2003). In the context of inter-firm partnerships, a structural bridge is created when a company is connected to another company while the first company is not directly connected to any of the other companies in its partner's network. According to the weak ties approach, stronger ties are less likely to act as a bridge, because two companies connected through a strong relationship are expected to become familiar with the other companies in each other's network (Granovetter, 1973). If the connection between two companies is a strong tie, additional partnerships are expected to gradually form between both companies and the other companies in their networks. As a result, the tie between both companies will no longer function as a structural bridge because of the frequency of interaction with others and the tendency for similarity in the networks of these strongly tied companies. The connections of one of the two main companies with various other companies will become similar as they will interact frequently through partnerships while also creating partnerships with the other main company. Through this interaction companies create interrelated local networks that, according to the weak ties approach, are running the risk of containing a high degree of redundancy.

Due to their structural properties, weaker ties are more likely to link companies to different local networks than stronger ties that are found between companies that share similarities in their partnerships (Granovetter, 1973; Krackhardt, 1992). Weaker ties also involve lower levels of interaction that do not depend on similarity between companies. Therefore, companies connected by weak ties are more likely to be dissimilar because they are not embedded in the same interconnected network of partnerships that are, to some extent,

shaped by similarities. Consequently, weaker ties are more likely to connect distant companies with diverse and unique perspectives, different activities, and diverse problem-solving styles (Granovetter, 1982; Ruef, 2002).

These weaker ties also give access to a wider range of potential partners and more, non-redundant information (Burt, 1992; Granovetter, 1973 and 1982; Weimann, 1983). Granovetter (1973) demonstrates this point, using the argument that the best way to spread gossip is through weak ties. If we understand gossip to be only a specific form of information, then information flowing through a strongly tied network tends to be redundant and travel circular paths as a company will tend to receive the same information from different companies. However, the information that passes through a weaker connection that acts as a structural bridge will reach different companies and not circulate back to its source. This information is expected to reach more and more companies that are farther removed from the original source of information. From the perspective of the company at the receiving end of the exchange, information travelling across a weak connection is more likely to be new and diverse relative to what the company is already aware of, because it emerges from distant companies outside the company's local network (see also Granovetter, 1982; Weimann, 1983).

Gaining access to diverse local networks and to non-redundant information provided by weak ties should also facilitate a more diverse information gathering process, relevant for our understanding of innovation and the technological performance of companies. Exposure to different approaches and new perspectives can enhance important innovative skills, such as the ability to generate technological alternatives and to engage in flexible thinking (Granovetter, 1982; Hagedoorn and Duysters, 2002; Schilling and Steensma, 2001). Exposure to alternative technologies and different approaches may stimulate a company to pursue previously unexplored directions, to find unexpected knowledge spillovers, and to experiment

with new ideas in such a way that these weak ties have a positive effect on its technological performance (Feldman and Audretsch, 1999; Kogut, 2000; Liebeskind, Oliver, Zucker and Brewer, 1996; Ruef, 2002). This is similar to the effect of exploratory learning or non-routinized learning that involves changes in company routines and experimentation with new opportunities that change the capabilities of companies and increase their technological performance (Dodgson, 1993; March, 1991).

Interestingly, a small number of contributions seem to suggest exactly the opposite logic, where strong network ties of companies generate better results than weak ties. According to Krackhardt (1992), strong ties may be beneficial, for instance by providing a strong social environment and mutual support for network players. Larsson (1992) understands the importance of strong ties for entrepreneurial firms in the context of a long-term perspective on ties that creates relational trust and reciprocity in information exchange between partners. Kraatz's (1998) study of the US private higher education sector reveals that strong ties instead of weak ties enable organizations to better adapt to environmental changes as organizations with strong ties learn from their well-connected environment. Leung-Kwong Wong and Ellis (2002) found that weak ties did play a role in the initial search process for Sino-Hong Kong international joint ventures, but in the final selection process of partners, when trust became more important, decisions were primarily based on information provided by strong ties. Kale, Singh and Perlmutter (2000) stress that strong ties between companies create relational trust which then affects the degree to which companies can learn from their partnerships. Uzzi (1997) does not discuss inter-firm networks in the exact terms of the strength of ties, he focuses on the embeddedness of ties of interrelated firms, but his study does suggest that strong ties are more suited for creating trust, information transfer and learning. Jenssen and Koenig (2002), in their study of nearly one hundred entrepreneurs in Norway, also establish that strong ties are important channels for information transfer.

Bruederl and Preisendoerfer (1998) examined entrepreneurial companies in Germany and found strong ties, in terms of support from family and friends, to be crucial resources for small business formation. Hite and Hesterly (2001) argue that strong ties will play an important role at the initial stages of the growth of entrepreneurial firms when these strong ties can help these firms to overcome various challenges in terms of limited resource access and restricted financial support due to their liability of newness.

Also in the context of the effect of the strength of network ties on the technological performance of companies, at least part of the literature suggests a positive effect of strong ties on technological performance. Strongly tied networks tend to be densely populated with many companies that have a multitude of relationships with each other. This cohesion within networks involves somewhat similar information flows, joint activities and solid and reciprocal relationships that create a basis of trust between partners (see also Ahuja, 2000; Brass, Butterfield and Skaggs, 1998; Kale, Singh and Perlmutter, 2000). Since trust is an important basis for knowledge sharing and joint learning (Brass et al., 1998; Liebeskind, Oliver, Zucker and Brewer, 1996), companies can use their strong ties to take advantage of joint learning and knowledge spillovers, while avoiding the duplication of innovative efforts, to improve their technological performance. Through strong ties companies can initiate new joint R&D projects that share some common technological characteristics with their partners (Mowery, Oxley and Silverman, 1996; Stuart and Podolny, 1996). As companies with strong ties focus on joint innovative efforts, this will increase the competence and expertise in their technological domain (Rosenkopf and Nerkar, 2001) and improve their technological performance.

Given the moral hazard that companies face in R&D partnerships where they exchange knowledge and jointly set up research projects, trust, social embeddedness, multiple interactions, and strong ties may be necessary to curb the willingness of some to pre-maturely

defect from R&D partnerships but it also increases the willingness of partners to share information (Ahuja, 2000; Ring and Van de Ven, 1994; Pisano, 1989). Weak ties may create unexpected opportunities for technological innovation, but strong ties increase the exchange and sharing of knowledge with a variety of trusted partners. Strong ties between companies create economies of scale and scope, and they enrich the knowledge base of companies in their existing technological domain where the connection of a range of incremental innovations is crucial for the overall technological performance of companies (Chesbrough and Teece, 1996; Freeman and Soete, 1997; OECD, 1992; Teece, 1996). Hence, we can formulate the following central hypothesis of this paper:

H.1: The stronger the network ties that companies are involved in through their inter-firm R&D partnerships, the higher their technological performance.

THE MEASUREMENT OF TIE-STRENGTH

If one takes a closer look at the actual measurement of the strength of network ties of companies in the inter-firm networks literature, one finds that most studies use a rather 'simple' straightforward binary, categorical measurement. For instance, in their study of networks in the US steel and semiconductor industries, Rowley, Behrens and Krackhardt (2000) measure the strength of ties of companies in terms of the form of their inter-firm partnerships. Joint ventures, equity alliances and R&D partnerships are combined as strong ties, whereas weak ties are related to marketing and licensing agreements. Ruef (2002) measures the strength of network ties of more than 700 US entrepreneurs in a setting of either strong network ties through family linkages and friends or weak network ties through business associates. A somewhat similar measurement is used by Leung-Kwong Wong and Ellis (2002) who describe strong ties as familial connections and close family-type friendship.

Weak ties are understood as casual friends, business associates and acquaintances. Jensen and Koenig (2002) take an even narrower perspective, they indicate the strength of network ties of entrepreneurs according to the role played by acquaintances (weak ties) or friends or close friends (strong ties). Rao, Davis and Ward (2000) measure strong network ties of companies defecting from the NASDAQ stock market to the New York Stock Exchange through the sum of all their non-duplicated interlocking directorates with other companies. Board memberships by third party organizations are considered as weak ties.

A small number of studies in the inter-firm networks literature make an attempt to measure the strength of inter-organizational network ties beyond this setting in terms of dichotomies. For instance, Nohria and Garcia-Pont (1991) rate the strength of network ties at a one-dimensional, nine-point scale in terms of the inter-organizational interdependence through different types of inter-firm linkages. McEvily and Zaheer (1999) measure the strength of network ties as the frequency of interaction of respondents for firms with a specific group of their advisors. Bruederl and Preisendoerfer (1998) measure strong ties of entrepreneurial firms in multiple industries as an index of support from multiple sources, i.e. spouses or life-partners, parents, friends and relatives. Weak ties are measured in terms of an index of support from other multiple sources such as business partners, acquaintances, former employers, and former co-workers. Kraatz (1998) uses a multiple measurement of the strength of network ties for 230 liberal arts colleges, in terms of the age of their network, the size of their network and their network heterogeneity or network homogeneity.

Interestingly, Granovetter's original contribution already went further than these later studies when he introduced a multidimensional understanding of the strength of network ties. This approach was based on a 'probably linear' combination of the five dimensions of network tie strength, mentioned in the above (amount of time, emotional intensity, intimacy, reciprocity within a tie, and degree of similarity of the social circles in which partners reside).

Also, the individual and combined strength of these dimensions can be seen as a movement along a continuum from weak to strong ties (Granovetter, 1973). In other words, Granovetter's contribution seems to suggest both a continuous and a multidimensional understanding of the weakness or strength of network ties. The above indicates that compared to the breadth of the original description of the strength of network ties by Granovetter, the understanding and measurement of the strength of inter-organizational network ties in the current inter-firm network literature is, with only a few exceptions, of a rather narrow and binary nature. Given the importance of the analysis of the strength of network ties in social network theory and the impact of Granovetter's contribution on the management literature, it seems relevant to consider retaining some of the richness of the original understanding of this phenomenon. Obviously, Granovetter's contribution is not necessarily the ultimate standard against which all other attempts to measure the strength of network ties should be assessed. However, the ease with which large parts of the literature seem to equate a binary understanding of tie-strength with the original multidimensional and continuous interpretation, is somewhat surprising. At the same time, information exchange, (joint) search for new options, learning, the impact of the level of cooperation, the similarity of (sub-) networks, and the degree of interaction are frequently discussed in the broader theoretical context of the understanding of inter-firm network ties, which suggests that a more multi-dimensional approach can enrich our understanding of the degree to which companies forge particular network ties.

A multidimensional understanding of the strength of inter-firm network ties

As a first step towards a more multi-dimensional understanding of the strength of inter-firm network ties, one can translate Granovetter's original description of the characteristics of network ties to inter-firm relationships, for instance through R&D partnerships, and arrive at a set of parallel indicators. For instance, the amount of time invested in a relationship can be

determined by looking at the length of the history of the partnerships of a company, a frequently used indicator of the level of interaction with other companies (Chung, Singh and Lee, 2000; Gulati, 1995; Koka and Prescott, 2002). The intensity of the network ties of a company can be interpreted as the multitude of partnerships that a company has, which expresses the degree to which a company focuses on particular partners and has a special relationship with them through a number of partnerships (Dyer and Singh, 1998; Gulati, 1995; Hagedoorn and Duysters, 2002; Koka and Prescott, 2002; Soh, 2003).

Intimacy and the reciprocity within a relationship can be translated into the degree of cooperation through the organizational interaction of partners in terms of the share of the joint ventures of a company in all its partnerships. Contractor and Lorange (2002), Dussauge and Garette (1999), Hagedoorn (1993), and Osborn and Baughn (1990) discuss the relevance of the degree of inter-organizational interdependence and interaction for a range of inter-firm partnerships. Higher levels of inter-organizational dependence and organizational interaction are found in equity joint ventures and lower degrees of interaction refer to a range of other forms of partnering such as licensing agreements, second sourcing, and standard customer supplier agreements (see also Nohria and Garcia-Pont, 1991; Rowley et al, 2000).

The similarity of the social circles of partners can be captured by their cultural closeness and the similarity of these networks through partnerships with other companies. The degree of cultural closeness can be understood in terms of domestic partnership formation and international cultural closeness. Domestic partnership formation will denote the share of domestic partnerships in the total of partnerships in which a company engages. This indicates the degree to which a company is seeking for network ties outside its domestic domain that are culturally different and less familiar than the ties that it has with companies in its well-known domestic environment (Buckley and Casson, 2002; Contractor and Lorange, 2002). International cultural closeness characterizes the degree to which a company has established

partnerships with companies from countries that are culturally similar, or not (Kogut and Singh, 1988).

Similarity of the networks in which two or more companies find themselves can be understood in terms of their structural equivalence which indicates the degree of interaction with companies that operate in similar networks. Two firms are referred to as structural equivalent if they have identical ties to other firms. The actual measurement of structural equivalence specifies the degree to which a company finds itself in a network of inter-firm ties that overlaps with the network of other companies (Hagedoorn and Duysters, 2002; Knoke and Kuklinsky, 1982; Wasserman and Faust, 1994).

As suggested by other research that considers the strength of network ties in a multidimensional setting (for instance Marsden and Campbell., 1984), factor analytical methods can be applied to indicate the degree of coherence between these different measures of tie strength. With the outcome of this partial analysis, one can construct an index of the strength of different ties that preserves the multidimensional character of the strength of network ties. A possible redefining of the boundaries between these dimensions and a further improvement of our understanding of these indicators and measures, seem interesting directions for both theoretical and empirical research on the strength of inter-firm network ties. Obviously, the strongest ties are still those that reach the higher levels for these indicators and dimensions, the weaker ties stay at the lower levels. In addition to this, such an approach will enable us to measure the possible dissimilar effects of different dimensions of the strength of network ties.

RESEARCH METHODS

Population and data

We present a statistical analysis of a large international population of 1697 companies, from 39 countries, with a total number of 3282 R&D partnerships. The data on the R&D partnerships were obtained from the MERIT-CATI databank. 18.76% of these R&D partnerships are joint ventures and 81.24% are contractual R&D partnerships. Furthermore, 47.25% of these R&D partnerships are domestic partnerships, whereas 52.75% have an international nature. We study four sectors of industry: pharmaceuticals (55.60% of the partnerships and 49.09 % of the total number of sponsoring companies), computers (10.63% and 13.80%), semi-conductors (27.08% and 27.39%), and telecom (6.69% and 9.72%). These industries are generally accepted as high-tech industries because of their R&D intensity, their level of new product development, and their patent intensity (OECD, 1997). Our research covers the period 1990-2000 for R&D partnerships, with three additional years (2001-2003) for patents as the dependent variable, and a maximum of five additional years for some of the independent variables (1985-1989).

The MERIT-CATI databank contains information on thousands of technology-related inter-firm partnerships in various sectors, ranging from high technology sectors such as pharmaceutical biotechnology to less technology intensive sectors such as food and beverages. Various sources from the international financial and specialized technical press were consulted to systematically collect information on inter-firm partnerships. Within the databank, there is information on each partnership and some information on companies participating in these partnerships. Partnerships are defined as mutual interests between independent companies that are not linked through majority ownership. Agreements formed between companies and governmental or academic institutions are generally not included in the database unless they involve at least two commercial companies. The current CATI

database only records those partnerships that involve some form of jointly undertaken R&D. Information is primarily collected on joint ventures with R&D activities and contractual R&D partnerships such as R&D pacts and joint development agreements. Other types of agreements such as production and marketing partnerships are not included. In other words, this material is primarily related to R&D collaboration and technology development, i.e. those partnerships for which a combined innovative activity is at least part of the agreement (see also Hagedoorn, 2002).

There are several reasons for choosing these four international high-tech sectors and R&D partnerships as the empirical setting for our study. First, some recent studies suggest that strong ties are perhaps less relevant in high-tech industries than in other industries (Hagedoorn and Duysters, 2002; Rowley, Behrens and Krackhardt, 2000; Walker, Kogut and Shan, 1997). As our hypothesis suggests quite the opposite, testing the effect of strong ties on technological performance in high-tech industries seems an appropriate setting for falsification purposes. Second, R&D partnerships build a dominant sub-category of partnerships in these high-tech industries (Hagedoorn, 1993) where there are also quite a large number of these partnerships, which enables us to test our central hypothesis on a large population. Third, given the internationalization of many industries, in which inter-firm partnerships play a significant role, it seems appropriate to analyze inter-firm network ties in an international context (OECD, 1992).

Dataset

As mentioned in the above, the dataset consists of 1697 companies that sponsor 3282 R&D partnerships. Each company has at least one R&D partnership and one partner. In order to test the hypotheses, we constructed a firm-level dataset. As our analysis focuses on companies, the measurements of dyadic indicators are assigned to both partners. This procedure enables us to recalculate all variables from the dyadic (pair) level to the level of individual companies, i.e.

all 1697 companies. For each company, we calculated the average value of each variable for each year that the company was involved in R&D partnerships. If company X had more than one R&D partnerships in a particular year, we calculated an average value for company X for that year. For some indicators, such as the R&D expenditures within a year, the average values are not affected by the number of events, whereas the average value for a variable such as structural equivalence is affected by the number of partners that each company has within its own ego-network.

Our dataset is not a panel dataset because for each year it only contains information on a company if it had at least one R&D partnership during that year. If we look at the population of 1697 companies, a large number of those companies had R&D partnerships scattered over the period 1990-2000. We cannot generate a panel dataset as there are a large number of companies, even some large companies, that have only established R&D partnerships in one or two years, instead of each year or nearly all years during the whole period. By using panel data we would be confronted with such a large number of non-occurrences that would make it impossible to run the statistical analysis. The alternative would be to remove the companies with a small number of R&D partnerships from the dataset. However, these companies are part of the overall network of R&D partnerships and deleting these companies from the dataset would not only seriously limit the number of companies, it would also have an artificial effect on all measures for network strength. In the end, we would arrive at a heavily biased dataset that would ignore a large part of the relevant population of companies with R&D partnerships.

Dependent variable

Our hypothesis associates the tie strength of the R&D partnerships of companies with their technological performance. The technological performance of companies is measured by means of their patent applications. Research by Hagedoorn and Cloudt (2003) indicates that,

in high-tech sectors such as those studied in this paper, counts of patents are adequate indicators of the overall technological performance of companies. The actual measurements are the number of patents that a company has obtained one year after it established one or more R&D partnerships (variable patents 1), the number of patents that a company has obtained within the two years after it formed at least one R&D partnership (patents 2), and the number of patents that a company obtained within the three years after it set up one or more R&D partnership (patents 3). These different time lags between joint R&D and patent applications are based on suggestions in the literature (Cincera, 1997; Hall, Griliches and Hausman, 1986; Scherer, 1984).

Given these time lags, the regressions for patents 1 have a one-year time lag after a company was engaged in establishing at least one R&D partnership in any year during the period 1990-2000, with 2000 as the last year for the formation of R&D partnerships and 2001 as the last year for patent counts. For patents 2 we take a two-year time lag after a company established at least one R&D partnership in any year during the period 1990-2000, with 2000 as the last year for the formation of R&D partnerships and 2001 and 2002 as the last two years for patent counts. For patents 3 we take a three-year time lag after at least one R&D partnership was established in any year during the period 1990-2000, with 2000 as the last year for the formation of R&D partnerships and 2001-2003 as the last three years for patent counts.

Data on patents are taken from the US Patent and Trademark Office (USPTO). Although this US data could imply a bias in favour of US companies and against non-US firms, the patent literature suggests several reasons to choose US patent data (see Patel and Pavitt, 1991). These reasons include the importance of the US market, the genuine patent protection offered by US authorities, and the level of technological sophistication of the US market, which makes it almost compulsory for non-US companies to file patents in the USA.

Independent variables, indicators and measures

For each R&D partnership established in a specific year, we calculated the value of each of the six tie strength indicators for each company that engages in that specific partnership. Some variables were first measured as dyadic or pairwise-country indicators. However, in order to carry out a firm-level analysis, the values of these measures were assigned to both companies engaging in the partnership. In case a company has more than one partnership per year, we calculated the average value for each indicator per company for that year. The reason for calculating average values per company for that specific year is that our unit of analysis is the company, and not pairs of companies that engage in a partnership, i.e. we need *one* value per company for that year in our dataset. These average values of the six indicators are then used to measure the strength of network ties for each company for that year.

The indicator length is the average duration of the period that a company has partnerships with each of its partners, going back to a maximum of five years before the start of the period covered by our research (see also Gulati, 1995). For each company, this is measured for each year that it is involved in R&D partnerships.

The indicator multitude measures the average number of multiple partnerships that a company has with other companies. This equals the degree centrality (total number of partnerships) divided by the number of its partners. For each company, this is measured for each year that it is involved in one or more R&D partnerships,

The degree of cooperation through organizational interaction indicates for each company, for the year that the company is involved in one or more R&D partnerships, the average value of the share of joint ventures in the total number of partnerships in which a company engages.

Network similarity is measured using the standard network indicator, structural equivalence. This measure is calculated by means of Pearson correlations that indicate the

actual similarity of the networks of R&D partnerships of companies. This procedure takes a company's row and column entries in a similarity matrix, compares them to the row and column entries of all other companies in the matrix and then calculates the degree of profile similarity between a company and each of the other companies. This comparison is made between every possible pair of companies in the matrix and the resulting profile similarity between each pair is measured using the Pearson product correlation coefficient for each pair. The greater the correlation for a pair of companies, the more structurally equivalent they are (Borgatti, Everett and Freeman, 2002; Hanneman, 2001).

It is important to keep in mind that our unit of analysis is at the firm level, and not at the pair-level. In order to make a firm-level analysis possible, the pairwise Pearson correlations are assigned to each individual company participating in the partnership, after which the average value is calculated per company for an event year. The resulting variable network similarity is the, per company, average value of these Pearson correlations for that particular year.

Cultural closeness can be measured by two indicators: international cultural closeness and domestic partnership formation. International cultural closeness measures the degree to which a company has established partnerships with companies from countries that are culturally similar. This measure uses the cultural distance formula from Kogut and Singh (1988) based on the four dimensions introduced by Hofstede (1980). Because this indicator should measure cultural closeness and not cultural differences as in the Kogut and Singh measure, a negative of the value is used to indicate that higher values indicate higher cultural closeness, i.e. stronger ties.

This measure is in principal a pairwise-country measure, because for each pair (and from both partners' country perspective) we can calculate this value for cultural closeness. However, for a firm-level analysis, these measures for cultural closeness are assigned to each

individual company in each partnership, which generates the average value per company for the year that the company is involved in R&D partnerships. The resulting variable cultural closeness is the average value of the cultural closeness per company for that year.

Domestic partnership formation indicates for each company, for the year that the company is involved in one or more R&D partnerships, the average value of the share of domestic partnerships in the total number of partnerships in which a company engages.

In order to translate these multiple indicators of the strength of network ties into more general dimensions of network ties, we first perform an exploratory factor analysis to see which indicators contribute to the same factor or dimension. It is expected that the measures length and multitude both contribute to the same factor, i.e. the factor time. The measures for the degree of cooperation and similarity of network ties are expected to contribute to the intensity of the network tie, i.e. they both contribute to the factor depth. Finally, the two indicators of cultural closeness, i.e. international cultural closeness and domestic partnership formation are expected to contribute to a third factor, labelled factor cultural closeness. For all measures and factors, higher values indicate stronger network ties.

Control variables

Consistent with prior research on inter-firm partnerships, we included a number of control variables for specific company characteristics, for some general characteristics of the sectors of industries and the countries from which companies originate. R&D expenditures of companies are taken as a control variable because we expect that their R&D expenditures are likely to be a significant determinant of their technological performance. Studies by Bound, Cummins, Griliches, Hall and Jaffe (1984), Griliches (1998), Hausman, Hall and Griliches (1984), Kamien and Schwartz (1982), and Scherer (1984) indicate a direct relation between the R&D efforts of companies and their patenting output, although the relation may not be a linear one. The variable R&D is measured by a company's R&D expenditures. In order to

compare R&D expenditures of companies from different countries, all R&D expenditures are transformed into US\$.

The literature indicates that the size of companies plays a role in the technological performance of companies. In that context it is argued that the patenting activity of companies increases with size (Cohen and Levin, 1989; Mansfield, 1986; Mueller, 1986; Scherer, 1984). The control variable size is measured in terms of the number of employees of a company. Information on the R&D expenditure and the size of companies was accessed through well-known databases such as Amadeus, Compustat, Disclosure, Osiris, and Worldscope.

The relevance of patenting differs with regard to sectors (Cohen, Nelson and Walsh, 2000; Teece, 1987; Winter, 1987). In order to control for this, we included the variable patents sector, which measures the number of USPTO patents at the sector level.

For a somewhat similar reason, we included the variable patents country, which is measured by the number of USPTO patents applied for by companies from each country.

RESULTS

Table 1 presents the descriptive statistics and the correlation matrix for the variables of the exploratory factor analysis. The descriptive statistics and the correlation matrix for all variables in the regression analysis are found in table 3.

----- insert table 1 about here -----

Table 2 provides the results of the exploratory factor analysis. Data used for factor analysis have to be tested for sampling adequacy and significance (Hair, 1995). The Kaiser-Meyer-Olkin measure of sampling adequacy and the anti-image correlations for the different measures are above the minimum level of 0.500. As can be seen in table 2, all communalities

are also above 0.500, i.e. all variables have sufficient explanation in the model. Our analysis results in three factors with an eigenvalue larger than 1, i.e. our model contains three significant factors. We interpret these factors as the factor time, the factor depth, and the factor cultural closeness. These three factors explain 65.39% of the total variance. Not surprisingly, the factor loadings exhibit the same overall pattern as the communalities (see table 2). According to common social science practice, that uses a minimum cut-off point of 0.30 or 0.35 for factor loadings, our factor loadings are very high and very significant, making all variables very representative of the three factors (Hair, Anderson, Tatham and Black, 1995). We use the resulting factor scores to represent the factors in our subsequent statistical analyses.

----- insert table 2 about here -----

As the dependent variable refers to the number of patents, i.e. the dependent variable is a non-negative, integer-valued count variable, we will use a count data model. After testing our data for over-dispersion, it turned out that the negative binomial model is to be preferred to the Poisson model (Cameron and Trivedi, 1986).

----- insert table 3 about here -----

Tables 4, 5, and 6 present the results of the negative binomial analysis with patents 1 (one year time lag), patents 2 (two years time lag), and patents 3 (three years time lag) as dependent variable, respectively. With very few minor exceptions the three tables tell much the same story. In tables 4-6, model 1 only includes the control variables, models 2, 3, and 4 each include one of the three factors or network variables, and model 5, the full model

includes the control variables and all three factors. In each table, adding one of the factors or network ties variables to the basic model, with only the control variables, improves the loglikelihood of the model significantly. The results of a chi-squared test for improvement of subsequent models are also reported in tables 4-6. Compared to the other models, model 5, the full model, has the highest log likelihood value.

----- insert table 4 about here -----

----- insert table 5 about here -----

----- insert table 6 about here -----

These findings generate partial support for the central hypothesis of this paper. The factor depth, which refers to the degree of cooperation by means of joint ventures and the similarity of networks, has a significant and positive effect on the technological performance of companies in all relevant models. The factor time, referring to the length of partnerships and the multitude of partnerships between companies, has a significant and positive effect in all but one of the relevant models. Obviously, both factors indicate that strong ties have a significant, positive effect on technological performance, but the factor depth (the degree of cooperation through joint ventures and the similarity of networks) appears to have the highest impact.

Interestingly, the factor cultural closeness, the degree of domestic partnership formation and the international cultural closeness, has a significant negative effect on the technological performance of companies in all relevant models. This implies that from the

perspective of cultural closeness, the weaker the network ties and the more international the ties of companies, the higher their technological performance.

As for the effects of the control variables, it turns out that the variable for R&D expenditures has a significant negative impact on the technological performance of companies. Additional analysis with a squared term for this variable, not reported here, does indicate a non-linear relationship between R&D expenditures and the dependent variable. This finding is consistent with the well-known literature in which R&D expenditures demonstrate an inverse U-shaped function of the technological performance of companies (Scherer, 1984). For companies with a relatively low level of R&D expenditures, an increase in R&D expenditures will result in an increase in technological performance. However, for companies that already have a relatively high level of R&D expenditures, a further increase of these expenditures will have a negative effect on their technological performance.

As expected, the control variables size and sectoral patenting both have a significant positive impact on the technological performance of companies. The last control variable, patenting at the country level, does not have a significant effect on the technological performance of a company, i.e. we cannot conclude that higher levels of patenting at the country level will result in higher technological performance of companies from these countries.

We also experimented with some possible interaction effects that could indicate that the strength of network ties would work out differently, for instance in combination with sectoral patenting activity. However, none of the potentially interesting interaction effects tuned out to generate significant results.

DISCUSSION AND CONCLUSIONS

Interestingly, some of the main findings of this study regarding the effect of the strength of network ties in an inter-firm network setting are somewhat similar to those presented in previous research on intra-organizational network ties of groups or departments within companies. For instance, Hansen (1999) demonstrates that there is no unequivocal answer to the question whether strong or weak ties between business units within a company increase its technological performance. However, his research does show that strong ties between business units facilitate the transfer of complex knowledge that in itself can contribute to an improved technological performance of the company. Somewhat comparable results are generated by Tsai (2001) who shows that business units within companies that maintain a large number of intra-organizational ties benefit from these ties through shared learning and extensive information exchange that improve their innovative output.

At the level of inter-organizational networks, when we consider the effect of the strength of inter-firm network ties in R&D partnerships, some aspects of strong ties do indeed also improve the technological performance of companies. More precisely: strong ties in inter-firm R&D partnerships improve, through their depth and time-related dimensions, the technological performance of companies in high-tech industries. In particular the strength of the R&D network ties of companies in terms of the depth of these ties has a positive effect on their technological performance. This depth-dimension of network ties refers to the combined effect of the degree of cooperation between companies and the similarity of their network ties and those of their partners. The intensive inter-organizational interaction by means of equity joint ventures (Contractor and Lorange, 2002; Dussauge and Garette, 1999; Osborn and Baughn, 1990; Rowley et al, 2000) and the similarity of the network ties of companies (Ahuja, 2000; Saxton, 1997; Uzzi, 1997), the interaction with a similar group of companies as their partners interact with, enables companies to benefit from their network ties.

The second important dimension of strong inter-firm network ties, the aspect of time denotes the joint, positive effect of the amount of time invested in inter-firm relationships and their intensity or multitude (see also Chung, Singh and Lee, 2000; Dyer and Singh, 1998; Gulati, 1995; Koka and Prescott, 2002; Soh, 2003). The length of the history of partnerships and their multitude, that express the degree to which companies have a special relationship with each other, also have a significant effect on the technological performance of companies.

These cohesive and strongly tied networks of R&D partnerships encourage information flows, knowledge sharing, and joint learning through reciprocal and trusted relationships (Kale, Singh and Perlmutter, 2000; Ring and Van de Ven, 1994; Pisano, 1989). Information flows, knowledge creation and learning are important to innovation in many industries but in particular in high-tech industries. Joint R&D activities through partnerships that combine these elements of the innovation process have become popular in many high-tech industries (Hagedoorn, 2002; Liebeskind, Oliver, Zucker and Brewer, 1996; Soh, 2003). Through strong ties, companies initiate joint R&D projects and other shared innovative activities that increase their technological performance in these industries within a relatively short period of time.

Although, the strength of these network ties only refers to some aspects of social embeddedness or social capital (see Adler and Kwon, 2002), these results do indicate that the social embeddedness of companies can indeed positively influence their technological innovative performance (Ahuja, 2000; Chung, Singh and Lee, 2000; Walker, Kogut and Shan, 1997). Our findings confirm the view on social embeddedness which implies that the higher the degree of social cohesiveness in a network environment, based on the density of ties, their common history, their interaction, and their similarity of partnerships, the more companies will benefit from the advantages created by the spillovers in their network environment. Companies with well-embedded R&D network ties, characterized by solid, reciprocal, dense,

and long-term trustworthy relationships do seem to benefit from the network externalities created by their R&D partnerships with a variety of companies.

As briefly discussed in the above, some previous research on intra-organizational network ties within companies (Hansen, 1999) reveals that there is probably no unambiguous answer to the question whether strong or weak ties increase the technological performance of companies. Our discussion of the literature on inter-organizational networks indicated that the research on the strength of inter-firm network ties has generated somewhat of a mixed bag. At first sight, our study does not seem to change that perception as two dimensions of tie strength (depth and time) support a strong ties perspective, whereas the third dimension of tie strength (cultural closeness) goes in the opposite direction. However, the counter intuitive nature of this finding, from a strong tie perspective, can be explained in the context of a complex learning environment in which many high-tech companies operate.

In a complex learning environment, a diversity of knowledge inputs from various sources is helpful to develop new technologies (Miller, 1996). International aspects of this learning environment expose companies to important new and diverse ideas from multiple markets and different cultural perspectives (Hagedoorn and Duysters, 2000; Hitt, Hoskisson, Johnson and Moesel, 1996). Ghoshal (1987) and Hoecklin (1995) state that the diversity of international environments and cultures in which a company operates exposes it to multiple stimuli. It enables the company to develop diverse capabilities and it provides a broader learning opportunity than is available to a company that operates in a purely domestic environment. Hoskisson and Hitt (1994) show that multinational companies can exploit differences in national resources and competencies to generate the additional resources necessary to successfully operate large-scale R&D in an international context.

The environment pictured in the above, is relevant for a large number of industries but in particular for many high-tech industries that have become highly internationalized during

the past decades (OECD, 1992). Although, our finding on the relevance of weak, internationally distant, network ties for the technological performance of companies seems surprising, it does indicate the importance of internationally diverse knowledge sourcing in these high-tech industries. Similar findings are reported in a recent study by Contractor, Kim and Beldona (2002) on the international pharmaceutical and chemical industries, where international R&D alliances yield higher innovative returns than domestic alliances. In combination with our results, these findings suggest that companies participating in international R&D partnerships with companies that are culturally distant have to engage in inter-organizational learning as they are confronted with new ideas from a variety of international markets and culturally different perspectives. Companies that use this diversity in external, international resources through joint innovative activities realize a higher technological performance than companies that participate in R&D partnerships with domestic companies or companies that are culturally close.

In international high-tech industries, companies that are well-embedded in long-term R&D relationships within a cohesive network generate higher technological performance than those that are less embedded. Yet, in this age of international markets and international technology sourcing, it is important for companies to put this embeddedness in a broader international perspective, as a predominance of domestic R&D partnerships can have a negative effect on the technological performance of companies. In other words, a combination of well-embedded strong R&D network ties, characterized by solid, reciprocal, dense, and long-term trustworthy relationships, within a setting of international and culturally diverse inter-firm R&D partnerships seems to be beneficial for the technological performance of companies operating in high-tech industries.

The above also indicates why it is not that much of a surprise that the empirical literature on the effect of the strength of inter-firm network ties generates rather conflicting

insights. Most of the relevant studies use only one indicator of the strength of network ties, very often a binary measurement, nearly always in a domestic setting. In a complex international environment with a multitude of inter-firm relationships through a variety of organizational forms, the notion of a multidimensional understanding of the strength of network ties appears more adequate to capture this complexity than a simple one-dimensional measurement that seems merely born out of convenience. However, our findings also suggest that such a multidimensional understanding of the strength of network ties does not conform to a ‘probably linear’ combination of the different dimensions of tie-strength, as stated in Granovetter (1973). As discussed in the above, a combination of stronger and weaker network ties is probably most beneficial. Furthermore, contrary to the general idea behind Granovetter’s theory of weak ties there is little evidence that the weakness of inter-firm network ties as such generates the expected positive returns to companies.

Obviously, there are a number of options for future research on this topic. Our research considers the effect of the strength of network ties on the technological performance of companies without differentiating between ‘run-of-the-mill’ innovations and radical innovations. The possible effect of network ties on radical innovations that shape the future of industries and that alter the position of companies is an interesting subject for subsequent research. Also, future research could consider a wider range of inter-firm partnerships that cover marketing, production, supply and for which the strength of network ties could perhaps have a different effect on the performance of companies. As noted in the above, much of the literature on tie strength has focused on inter-personal relationships within organizations whereas our contribution considers the effect of network ties in an inter-organizational context. A further extension of a multi-dimensional approach could benefit from research that would link inter-personal aspects of network ties with the different aspects of inter-organizational network ties that are analyzed in this paper.

REFERENCES

- Adler, P.S. and S-W. Kwon, 2002, Social capital: prospects for a new concept, *Academy of Management review*, 27, 17-40.
- Ahuja, G., 2000, Collaboration networks, structural holes, and innovation: a longitudinal study, *Administrative Science Quarterly*, 45, 425-455.
- Borgatti, S.P., Everett, M.G. and L.C. Freeman, 2002, *Ucinet for Windows Version 6.29: Software for Social Network Analysis*, Harvard, MA: Analytic Technologies.
- Bound, J., Cummins, C., Griliches, Z., Hall, B.H. and A. Jaffe, 1984, Who does R&D and who patents?, in Griliches, Z. (ed.), *R&D, patents, and productivity*, University of Chicago Press, Chicago, 21-54.
- Brass, D.J., Butterfield, D.D. and B.C. Skaggs, 1998, Relationships and unethical behavior: A social network perspective, *Academy of Management Review*, 23, 14-31.
- Bruederl, J. and Preisendoerfer, P., 1998, Network support and the success of newly founded businesses, *Small Business Economics*, 10, 213-225.
- Buckley P.J. and Casson, M., 2002, A theory of cooperation in international business, in: Contractor, F.J. and P. Lorange (eds.), *Cooperative strategies and alliances in international business*, 2002, Elsevier Science, Amsterdam, 31-53.
- Burt, R.S., 1992, *Structural holes: the social structure of competition*, Cambridge (MA), Harvard University Press.
- Cameron, A.C. and P.K. Trivedi, 1986, Econometric models based on count data: comparisons and applications of some estimators and tests, *Journal of Applied Econometrics*, 1, 29-53.
- Chesbrough, H. and D. Teece, 1996, When is virtual virtuous: organizing for innovation, *Harvard Business Review*, January-February, 65-74.

Chung, S., Singh, H. and K. Lee, 2000, Complementarity, status similarity and social capital as drivers of alliance formation, *Strategic Management Journal*, 21, 1-22.

Cincera, M., 1997, Patents, R&D, and technological spillovers at the firm level: some evidence from econometric count models for panel data, *Journal of Applied Econometrics*, 12, 265-280.

Cohen, W.M. and R.C. Levin, 1989, Empirical studies of innovation and market structure, in: Schmalensee, R. and R. Willig (eds.), 1989, *Handbook of industrial organization*, 2, Elsevier, Amsterdam, 1059-1107.

Cohen, W.M., Nelson R.R. and J. P. Walsh, 2000, *Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)*, Cambridge (MA), National Bureau of Economic Research, working paper 7552.

Contractor, F.J., Kim, C. and S. Beldona, 2002, Interfirm learning in alliances and technology networks: An empirical study in the global pharmaceutical and chemical industries, in: Contractor, F.J. and P. Lorange (eds.), *Cooperative strategies and alliances in international business*, 2002, Elsevier Science, Amsterdam, 493-516.

Contractor, F.J. and P. Lorange, 2002, *Cooperative strategies and alliances in international business*, 2002, Elsevier Science, Amsterdam.

Dodgson, M., 1993, Organizational learning: a review of some literatures, *Organization Studies*, 14, 375-394.

Dussauge, P. and B. Garette, 1999, *Cooperative Strategy: Competing successfully through strategic alliances*, Chichester, Wiley.

Dyer, J.H. and H. Singh, 1998, The relational view: cooperative strategy and sources of interorganizational competitive advantage, *Academy of Management Review*, 23, 660-679.

Feldman, M.P. and D.B. Audretsch, 1999, Innovation in cities: science-based diversity, specialization, and localized competition, *European Economic Review*, 43, 409-429.

Freeman, C. and L. Soete, 1997, *The economics of industrial innovation*, London, Pinter.

Gomes-Casseres, B., 1996, *The alliance revolution: the new shape of business rivalry*, Cambridge, Harvard University Press.

Ghoshal, S., 1987, Global strategy: an organizing framework, *Strategic Management Journal*, 8, 425-440.

Granovetter, M.S., 1973, The strength of weak ties, *American Journal of Sociology*, 78, 1360-1380.

Granovetter, M.S., 1982, The strength of weak ties: a network theory revisited, in Marsden, P.V. and N. Lin (eds.), *Social structure and network analysis*, Beverly Hills (CA), Sage, 105-130.

Griliches, Z., 1998, *R&D and productivity: the econometric evidence*, The University of Chicago Press, Chicago.

Gulati, R., 1995, Social structure and alliance formation patterns: A longitudinal analysis. *Administrative Science Quarterly*, 40, 619-652.

Hagedoorn, J., 1993, Understanding the rationale of strategic technology partnering: inter-organizational modes of cooperation and sectoral differences, *Strategic Management Journal*, 14, 371–85.

Hagedoorn, J., 2002, Inter-Firm R&D Partnerships: An Overview of Major Trends and Patterns Since 1960, *Research Policy*, 31, 477-492.

Hagedoorn, J. and M. Cloudt, 2003, Measuring innovative performance: is there an advantage in using multiple indicators?, *Research Policy*, 32, 1365-1379.

Hagedoorn, J. and G.M. Duysters, 2002, Learning in dynamic inter-firm networks – the efficacy of multiple contacts, *Organization Studies*, 23, 525-548.

Hair, J.F., Anderson, R.E., Tatham, R.L., and W.C. Black, 1995, *Multivariate data analysis with readings*, Prentice-Hall, 4th edition, New Jersey, USA.

Hall, B.H., Griliches, Z. and J. Hausman, 1986, Patents and R&D, is there a lag?, *International Economic Review*, 27, 265-283.

Hanneman, R.A., 2001, Introduction to Social Network Methods, Department of Sociology, University of California, Riverside.

Hansen, M.T., 1999, The search-transfer problem: the role of weak ties in sharing knowledge across organization subunits, *Administrative Science Quarterly*, 44, 82-111.

Hausman, J., Hall B.H. and Z. Griliches, 1984, Econometric models for count data with an application to the patents-R&D relationship, *Econometrica*, 52, 909-938.

Hite, J.M. and W.S. Hesterly, 2001, The evolution of firm networks: from emergence to early growth of the firm, *Strategic Management Journal*, 22, 275-286.

Hitt, M.A., Hoskisson, R.E., Johnson R.A. and D.D. Moesel, 1996, The market for corporate control and firm innovation, *Academy of Management Journal*, 39, 1084-1119.

Hoecklin, J., 1995, *Managing cultural differences: strategies for competitive advantage*, Sage Publications, Workingham.

Hofstede, G.H., 1980, *Culture's consequences: international differences in work-related values*, Beverly Hills (CA), Sage Publications.

Hoskisson, R.E., and M.A. Hitt, 1994, *Downscoping: how to tame the diversified firm*, Oxford University Press, Oxford.

Ibarra, H. and S.B. Andrews, 1993, Power, social influence, and sense making: effects of network centrality and proximity on employee perceptions, *Administrative Science Quarterly*, 38, 277-303.

Jenssen J.I. and H.F. Koenig, 2002, The effect of social networks on resource access and business start-ups, *European Planning Studies*, 10, 1039-1046.

Kale, P., Singh, H. and H. Perlmutter, 2000, Learning and protection of proprietary assets in strategic alliances: building relational-specific capital, *Strategic Management Journal*, Special Issue, 21, 217-237.

Kamien, M.I. and N.L. Schwartz, 1982, *Market structure and innovation*, Cambridge, Cambridge University Press.

Knoke, D. and J.H. Kuklinsky, 1982, *Network analysis*, Sage Publications, Series: Quantitative Applications in the Social Sciences.

Kogut, B., 2000, The network as knowledge: generative rules and the emergence of structure, *Strategic Management Journal*, 21, 405-425.

Kogut, B. and H. Singh, 1988, The effect of national culture on the choice of entry mode, *Journal of International Business Studies*, 19(Fall), 411-432.

Koka, B.R. and J.E. Prescott, 2002, Strategic alliances as social capital: a multidimensional view, *Strategic Management Journal*, 23, 795-816.

Kraatz, M.S., 1998, Learning by association? Interorganizational; networks and adaptation to environmental change, *Academy of Management Journal*, 41, 621-643.

Krackhardt, D., 1992, The strength of strong ties: the importance of philos in organization, in Nohria, N. and R.C. Eccles (eds.), *Networks and organizations: structure, form, and action*, Boston (MA), Harvard Business School Press, 216-239.

Larson, A., 1992, Network dyads in entrepreneurial settings: a study of the governance of exchange processes, *Administrative Science Quarterly*, 37, 76-104.

Leun-Kwong Wong, P. and P. Ellis, 2002, Social ties and partner identification in Sino-Hong Kong international joint ventures, *Journal of International Business Studies*, 33, 267-289.

Liebeskind, J., Oliver, A., Zucker, L. and M. Brewer, 1996, Social networks, learning, and flexibility: Sourcing scientific knowledge in new biotechnology firms, *Organization Science*, 7, 428-443.

Mansfield, E., 1986, Patents and innovation: an empirical study, *Management Science*, 32, 173-181.

March, J., 1991, Exploration and exploitation in organizational learning, *Organization Science*, 2, 71-87.

Marsden, P. and K. Campbell., 1984, Measuring tie strength, *Social Forces*, 63, 482-501

McEvily B. and A. Zaheer, 1999, Bridging ties: a source of firm heterogeneity in competitive capabilities, *Strategic Management Journal*, 20, 1133-1156.

Miller, D., 1996, The embeddedness of corporate strategy: isomorphism vs. differentiation, *Advances in Strategic Management*, 13, 283-291.

Mowery, D.C., Oxley, J.E., and B.S. Silverman, 1996, Strategic alliances and interfirm knowledge transfer, *Strategic Management Journal*, 17 winter special issue, 77-91.

Mueller, D.C., 1986a, *The modern corporation-profits, power, growth and performance*, Wheatsheaf Books, Brighton.

Nelson, R.E., 1989, The strength of strong ties: social networks and intergroup conflict in organizations, *Academy of Management Journal*, 32, 377-401.

Nohria, N. and C. Garcia-Pont, 1991, Global strategic linkages and industry structure, *Strategic Management Journal*, 12, pp. 105-124.

OECD, 1992, *Technology and the economy*, OECD, Paris.

OECD, 1997, *Revision of high technology sector and product classification*, OECD, Paris.

Osborn, R.N. and C.C. Baughn, 1990, Forms of interorganizational governance for multinational alliances, *Academy of Management Journal*, 22, 503-519.

Patel, P. and K. Pavitt, 1991, Large firms in the production of the world's technology: An important case of non-globalization, *Journal of International Business Studies*, 22, 1-21.

Perry-Smith, J.E. and C.E. Shalley, 2003, The social side of creativity: a static and dynamic social network perspective, *Academy of Management Review*, 28, 89-106.

Rao, H., Davis, G.F. and A. Ward, 2000, Embeddedness, social identity, and mobility: Why firms leave the NASDAQ and join the New York Stock Exchange, *Administrative Science Quarterly*, 45, 268-292.

Ring, P.S. and A.H. Van de Ven, 1994, Developmental processes of cooperative inter-organizational relationships, *Academy of Management Review*, 19, 90-118.

Rosenkopf, L. and A. Nerkar, 2001, Beyond local search: boundary-spanning, exploration, and impact in the optical disk industry, *Strategic Management Journal*, 22, 287-306.

Rowley, T., Behrens, D. and D. Krackhardt, 2000, Redundant governance structures: an analysis of structural and relational embeddedness in the steel and semiconductor industries, *Strategic Management Journal*, 21, 369-386.

Ruef, M., 2002, Strong ties, weak ties and islands: structural and cultural predictors of organizational innovation, *Industrial and Corporate Change*, 11, 427-449.

Saxton, T., 1997, The effects of partner and relationship characteristics on alliance outcomes, *Academy of Management Journal*, 40, 443-461.

Scherer, F.M., 1984, Using linked patent and R&D data to measure interindustry technology flows, in Z. Griliches (ed.), *R&D, patents and productivity*, The University of Chicago Press, Chicago, 417-464.

Schilling, M.A. and H.K. Steensma, 2001, The use of modular organizational forms: An industry-wide analysis, *Academy of Management Journal*, 44, 1149-1169.

Shah, P.P., 1998, Who are employees' social referents? Using a network perspective to determine referent others, *Academy of Management Journal*, 41, 249-268.

Soh, P-H., 2003, The role of networking alliances in information acquisition and its implications for new product information, *Journal of Business Venturing*, 18, 727-744.

Stuart, T.E. and J.M. Podolny, 1996, Local search and the evolution of technological capabilities, *Strategic Management Journal*, 17, 21-38.

Teece, D.J., 1987, Profiting from technological innovation: the implications for integration, collaboration, and public policy, in Teece, D.J. (ed.), *The competitive challenge*, Cambridge (Ma), Ballinger.

Teece, D.J., 1996, Capturing value form technological innovation: integration, strategic partnering, and licensing decisions, in: Tushman, M.L. and P. Anderson (eds), *Managing Strategic Innovation and Change*, New York, Oxford University Press, 287-306.

Tsai, W., 2001., Knowledge transfer in intra-organizational networks: Effects of network position and absorptive capacity on business unit innovation and performance, *Academy of Management Journal*, 44, 996-1004.

Uzzi, B., 1997, The social structure and competition in interfirm networks: the paradox of embeddedness, *Administrative Science Quarterly*, 42, 35-67.

Walker, G., Kogut, B., W. Shan, 1997. Social capital, structural holes, and the formation of an industry network, *organization science*, 8, 109-125.

Wasserman, S. and K. Faust, 1994, *Social network analysis, methods and applications*, Cambridge University Press.

Weimann, G., 1983, The strength of weak conversational ties in the flow of information and influence, *Social Networks*, 5, 245-267.

Winter, S.G., 1987, Knowledge and competence as strategic assets, in Teece, D.J. (ed.), *The competitive challenge*, Cambridge (Ma), Ballinger.

Table 1 Descriptive statistics (means and standard deviations (S.D.)) and bivariate correlations for all variables of the exploratory factor analysis

| Variable | Mean | S.D. | 1 | 2 | 3 | 4 | 5 | 6 |
|------------------------------------|--------|-------|--------|--------|--------|-------|-------|-------|
| 1 Length | 0.167 | 0.681 | 1.000 | | | | | |
| 2 Multitude | 1.041 | 0.192 | 0.237 | 1.000 | | | | |
| 3 Degree of cooperation | 0.137 | 0.320 | -0.015 | -0.052 | 1.000 | | | |
| 4 Similarity of networks | 0.192 | 0.427 | 0.070 | 0.064 | 0.106 | 1.000 | | |
| 5 International cultural closeness | -0.764 | 1.037 | 0.001 | -0.070 | -0.002 | 0.004 | 1.000 | |
| 6 Domestic partnership formation | 0.462 | 0.459 | 0.046 | -0.066 | -0.024 | 0.030 | 0.643 | 1.000 |

Table 2 Estimation results of the exploratory factor analysis

| Variable | Communalities | | Factor Loadings | | |
|------------------------------------|---------------|--------------|---------------------------|--------------|---------------------------|
| | Factor Time | Factor Depth | Factor Cultural Closeness | Factor Depth | Factor Cultural Closeness |
| 1 Length | 0.589 | 0.765 | | | |
| 2 Multitude | 0.600 | 0.773 | | | |
| 3 Degree of cooperation | 0.554 | 0.732 | | | |
| 4 Similarity of networks | 0.561 | 0.738 | | | |
| 5 International cultural closeness | 0.808 | | | | 0.897 |
| 6 Domestic partnership formation | 0.811 | | | | 0.899 |
| Total Eigenvalue | 1.186 | 1.085 | | | 1.652 |
| % Variance explained | 19.774 | 18.086 | | | 27.532 |

Table 3 Descriptive statistics (means and standard deviations (S.D.)) and bivariate correlations for all variables of the negative binomial analysis

| Variable | Mean | S.D. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------------------------|-----------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|
| 1 Dependent variable: Patents 1 | 55.964 | 207.428 | 1.000 | | | | | | | | | |
| 2 Dependent variable: Patents 2 | 106.946 | 400.519 | 0.985 | 1.000 | | | | | | | | |
| 3 Dependent variable: Patents 3 | 150.856 | 577.253 | 0.952 | 0.987 | 1.000 | | | | | | | |
| 4 Factor time | -0.195 | 0.895 | 0.075 | 0.077 | 0.078 | 1.000 | | | | | | |
| 5 Factor depth | -0.233 | 0.550 | 0.368 | 0.363 | 0.352 | -0.138 | 1.000 | | | | | |
| 6 Factor cultural closeness | -0.543 | 0.917 | 0.010 | 0.008 | 0.009 | 0.049 | 0.110 | 1.000 | | | | |
| 7 R&D | 7.867 | 51.113 | 0.027 | 0.027 | 0.026 | 0.013 | -0.003 | -0.015 | 1.000 | | | |
| 8 Size | 8.405 | 2.805 | 0.412 | 0.404 | 0.397 | 0.150 | 0.198 | 0.054 | 0.203 | 1.000 | | |
| 9 Patents sector | 13355.755 | 9597.652 | 0.240 | 0.213 | 0.182 | 0.075 | 0.189 | 0.086 | 0.016 | 0.225 | 1.000 | |
| 10 Patents country | 79578.801 | 56698.758 | -0.043 | -0.046 | -0.050 | -0.468 | 0.041 | -0.146 | -0.048 | -0.307 | 0.004 | 1.000 |

Table 4 Estimation results of the negative binomial analysis (one-year time lag for the dependent variable)

| | Model 1: Control Variables | Model 2: Factor Time | Model 3: Factor Depth | Model 4: Factor Cult.Closeness | Model 5: Full Model |
|------------------------------|---|-------------------------------------|--------------------------------------|---|------------------------------------|
| Constant | -1.0730*** (0.1730) | -1.1937*** (0.1832) | -0.6902*** (0.2035) | -1.1575*** (0.1754) | -0.8911*** (0.2120) |
| Factor time | | 0.1459** (0.0703) | | | 0.1500** (0.0694) |
| Factor depth | | | 0.3192*** (0.0959) | | 0.3583*** (0.1019) |
| Factor Cultural closeness | | | | -0.2091*** (0.0626) | -0.2140*** (0.0628) |
| R&D | -0.0064*** (0.0022) | -0.0063*** (0.0021) | -0.0062*** (0.0021) | -0.0065*** (0.0021) | -0.0062*** (0.0021) |
| Size | 0.5001*** (0.0163) | 0.5032*** (0.0163) | 0.4764*** (0.0175) | 0.5088*** (0.0164) | 0.4870*** (0.0176) |
| Patents sector | 0.0496*** (0.0059) | 0.0475*** (0.0059) | 0.0447*** (0.0059) | 0.0495*** (0.0058) | 0.0425*** (0.0058) |
| Patents country | -0.0016 (0.0011) | -0.0002 (0.0013) | -0.0024** (0.0011) | -0.0018* (0.0011) | 0.0010 (0.0013) |
| Log likelihood (L) | -6246.039 | -6232.429 | -6228.321 | -6229.512 | -6220.585 |
| Log L change | | (2)-(1) | (3)-(1) | (4)-(1) | (5)-(1) |
| χ^2 | | 27.220**** | 35.436**** | 33.054**** | 50.908**** |

Standard errors in parentheses

- **** significant at $p < 0.001$;
- *** significant at $p < 0.01$;
- ** significant at $p < 0.05$;
- * significant at $p < 0.10$.

Table 5 Estimation results of the negative binomial analysis (two-year time lag for the dependent variable)

| | Model 1: Control Variables | Model 2: Factor Time | Model 3: Factor Depth | Model 4: Factor Cult.Closeness | Model 5: Full Model |
|------------------------------|---|-------------------------------------|--------------------------------------|---|------------------------------------|
| Constant | -0.2266 (0.1389) | -0.3160** (0.1456) | 0.2051 (0.1632) | -0.3078** (0.1408) | 0.2862 (0.1685) |
| Factor time | | 0.1223** (0.0575) | | | 0.1328** (0.0565) |
| Factor depth | | | 0.3774*** (0.0794) | | 0.4184*** (0.0843) |
| Factor Cultural closeness | | | | -0.2135*** (0.0515) | -0.2205*** (0.0517) |
| R&D | -0.0053*** (0.0010) | -0.0053*** (0.0010) | -0.0051*** (0.0010) | -0.0054*** (0.0010) | -0.0051*** (0.0010) |
| Size | 0.4907*** (0.0129) | 0.4952*** (0.0129) | 0.4639*** (0.0138) | 0.5000*** (0.0130) | 0.4740*** (0.0139) |
| Patents sector | 0.0454*** (0.0049) | 0.0435*** (0.0049) | 0.0401*** (0.0049) | 0.0452*** (0.0048) | 0.0378*** (0.0048) |
| Patents country | -0.0020** (0.0009) | -0.0008 (0.0011) | -0.0028*** (0.0009) | -0.0022** (0.0009) | -0.0017 (0.0011) |
| Log likelihood (L) | -7527.759 | -7507.669 | -7496.875 | -7502.129 | -7485.811 |
| Log L change | | (2)-(1) | (3)-(1) | (4)-(1) | (5)-(1) |
| χ^2 | | 40.180**** | 61.768**** | 51.260**** | 83.896**** |

Standard errors in parentheses

- **** significant at $p < 0.001$;
- *** significant at $p < 0.01$;
- ** significant at $p < 0.05$;
- * significant at $p < 0.10$.

Table 6 Estimation results of the negative binomial analysis (three-year time lag for the dependent variable)

| | Model 1: Control Variables | Model 2: Factor Time | Model 3: Factor Depth | Model 4: Factor Cult.Closeness | Model 5: Full Model |
|---------------------------|---|-------------------------------------|--------------------------------------|---|------------------------------------|
| Constant | 0.1419 (0.1407) | 0.0894 (0.1457) | 0.6007 (0.1664) ^{***} | 0.0595 (0.1429) | 0.4537 ^{***} (0.1705) |
| Factor time | | 0.0884 (0.0592) | | | 0.1046 [*] (0.0583) |
| Factor depth | | | 0.4210 ^{**} (0.0847) | | 0.4600 ^{***} (0.0895) |
| Factor cultural closeness | | | | -0.2197 ^{***} (0.0541) | -0.2291 ^{***} (0.0544) |
| R&D | -0.0055 ^{***} (0.0011) | -0.0055 ^{***} (0.0011) | -0.0053 ^{***} (0.0011) | -0.0057 ^{***} (0.0011) | -0.0054 ^{***} (0.0011) |
| Size | 0.5036 ^{***} (0.0132) | 0.5044 ^{***} (0.0133) | 0.4752 ^{***} (0.0142) | 0.5136 ^{***} (0.0134) | 0.4856 ^{***} (0.0144) |
| Patents sector | 0.0414 ^{***} (0.0052) | 0.0398 ^{**} (0.0053) | 0.0356 ^{**} (0.0052) | 0.0410 ^{***} (0.0051) | 0.0334 ^{***} (0.0052) |
| Patents country | -0.0029 ^{***} (0.0009) | -0.0020 [*] (0.0011) | -0.0038 ^{***} (0.0009) | -0.0032 ^{***} (0.0009) | -0.0030 ^{***} (0.0011) |
| Log likelihood (L) | -7898.880 | -7878.786 | -7865.488 | -7872.440 | -7855.912 |
| Log L change | | (2)-(1) | (3)-(1) | (4)-(1) | (5)-(1) |
| χ^2 | | 40.188 ^{****} | 66.784 ^{****} | 52.880 ^{****} | 85.936 ^{****} |

Standard errors in parentheses

- **** significant at $p < 0.001$;
- *** significant at $p < 0.01$;
- ** significant at $p < 0.05$;
- * significant at $p < 0.10$.